USEFUL INFORMATION FOR ENGINEERS.

THIRD SERIES.

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USEFUL INFORMATION

FOR ENGINEERS.

THIRD SERIES.

AS COMPRISED IN A SERIES OF LECTURES ON THE APPLIED SCIENCES; AND ON OTHER KINDRED SUBJECTS; TOGETHER WITH TREATISES ON THE COMPARATIVE MERITS OF THE PARIS AND LONDON INTERNATIONAL EXHIBITIONS, ON ROOFS, ON THE ATLANTIC CABLE, AND ON THE EFFECT OF IMPACT ON GIRDERS.

BY

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CHEVALIER OF THE LEGION OF HONOUR;
ETC. ETC.

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Edwin C. BROOKS
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TO

THE RIGHT HONOURABLE

THE LORD BROUGHAM AND VAUX, F.R.S.

MEMBER OF THE INSTITUTE OF FRANCE

&c. &c. &c.

This Third Series of Useful Information

IS INSCRIBED

BY HIS FRIEND

THE AUTHOR

PREFACE.

IN SUBMITTING a Third Series of 'Useful Information for Engineers' to the profession and the public, I have collected and recorded in the present more accessible form, a number of lectures and papers, some of which have been published and distributed in the transactions of various societies and institutions. Many of these refer to works of practical utility: they have cost much time and thought; and as some of them involve principles of applied science, I have endeavoured to render them more acceptable, in this shape, to the professional as well as the general reader.

In this publication I have endeavoured to follow the same course as that pursued in the former series, hoping that the contents may be found interesting and useful as matter of reference in constructive art. There are, moreover, other considerations in view, which may be summed up in a few remarks on the leading subjects to which they refer, and the principles on which the investigations and experimental researches are founded.

On referring to the lectures, it will be seen that they are almost exclusively intended for the moral and intellectual improvement of the Engineer and Artizan. They

were written for the exclusive purpose of urging them to go forward in a course of mental study and perseverance calculated for attaining that standard of character essential to the growing spirit of the age, and to keep pace with the times in these days of competitive industry, by which the manufacturing and commercial enterprise of the country is governed.

On these points I have dwelt with more than ordinary intensity, in order to enforce the necessity of accelerated progress in all those attainments which bear upon the moral and intellectual conditions of our daily pursuits.

To the lecture on Applied Science I would venture to direct special attention, as the object in view is to impress upon the mind of the student or apprentice the important duty of acquiring a knowledge of first principles, and the power to apply them; also, to make himself acquainted with the history of scientific men of the past and present age, and to follow up in his own profession the characteristic energy and perseverance which distinguished our most successful inventors and men of science. I have also attempted to show, in the concluding words of the lecture, the importance of a knowledge of physical truths; their immense value when successfully applied; and the consequent failures which necessarily follow in cases where the combination of first principles in practice is neglected.

The lecture on the present state of progress in Science and Art was written for the purpose of directing the attention of members of Mechanics' Institutions to the past and present condition of our acquirements on those subjects; and to show what has been done, and what yet

remains to be accomplished for the advancement of mechanical science.

In illustration of these objects, I have taken the varied forms of transit, from the pack-horse of former days to the waggon, carriage, and locomotive of the present: I have also noticed the introduction of Steam, Gas, and the Electric Telegraph, and such other discoveries as have influenced the wonderful attainments of the present generation of men.

In the lecture on 'Labour,' will be found a short analysis of mental, as compared with physical labour, and the results which follow from its acceptance and application to the general purposes of life; and, in order to prepare the rising generation for the duties of labour, an attempt is made to trace the functions of the mind through the outward senses, and to encourage by judicious exercise those faculties which require development, and which tend to the enlargement of the intellect, and the successful cultivation of laborious pursuits.

Examples are also given to show that labour is inherent in every condition of animated existence, that its exercise is invigorating and healthy, that its influence is powerful, and that its achievements are great.

In the address delivered at the inauguration of the Southport 'Athenæum,' I have endeavoured to exhibit the advantages of Literary and Scientific Institutions, and to show that a careful application to study in reading, writing, and meditation, is the only road to distinction, and that an untiring industry, and a high sense of honour are the only true harbingers of success.

The other two lectures, one 'On the Thickness of the

Earth's Crust,' and the other 'On Iron and its Appliances,' were delivered to the members of the Literary and Philosophical Society of Newcastle-upon-Tyne. In the former researches is recorded the attempt made by Mr. Hopkins, of Cambridge, and myself, to determine experimentally the temperature of fluidity in bodies when subjected to severe pressure, and from this and the known increase of temperature as we penetrate vertically from the surface downwards, to deduce the approximate thickness of the earth's crust. Mr. Hopkins laboured with unwearied perseverance for several years at this enquiry; and the results, which must be considered approximate, will be found recorded in the Philosophical Transactions, and those of the British Association for the Advancement of Science.

Iron appliances is a large subject on which volumes may be written: its treatment in a lecture must of necessity be limited, and its application still more confined: a few facts are, however, given in connection with its uses when applied to the steam engine, millwork, and machinery; and, what is of some importance to engineers and miners, is its value in the construction of large beams for pumping-engines, where new and useful examples are given for the employment of wrought instead of cast iron in cases of structure where danger is imminent.*

The remaining papers which constitute the volume are almost entirely composed of writings and experimental

* This paragraph refers to the unfortunate accident which occurred at the Hartley Colliery some years since, where upwards of 400 persons lost their lives through the breaking of the cast iron Engine Beam.

researches for which I am alone responsible. They consist of documents in connection with practical science which may be enumerated in reports such as 'The comparative merits of the Machinery of the Paris Universal Exhibition of 1855,' and that of 'The Machinery Department of the South Kensington Exhibition of 1862.' To these are added a Treatise on Iron Roofs, Researches on the Insulation of Submarine Cables (undertaken at the request of the Atlantic Telegraph Company) and experiments to determine the effect of impact, vibratory action, and long-continued changes of loads on wrought iron girders.

All these communications had a special interest at the time they were written; and, as they are founded on subjects of practical utility, I may venture to hope that as points of reference they may prove interesting to the general reader, and others connected with constructive art, and the commercial enterprise of the country.

In conclusion I have to state that my acknowledgments are due to Mr. EDWARD W. JACOB, my assistant, for the efficient manner in which the drawings and illustrations have been prepared, and for other matters connected with the publication.

W. F.

MANCHESTER,
Sept. 30, 1866.

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ON

THE ADVANTAGES

OF

APPLIED SCIENCE.

LECTURE I.

ON THE APPLIED SCIENCES.

By the term Science we express our knowledge of first principles, or those laws which govern the movements, combinations, and structural condition of bodies; and by the word Application we mean that the knowledge thus obtained is rendered useful in the adaptation of those laws to the purposes of construction and the advancement of industrial art. It may be interesting to show how the power of man has been augmented by each new discovery that has taken place in the history of science, and it must be remembered that, when we speak of new discoveries and new inventions, it does not imply that anything new is created; it only means that we have discovered or found out laws unknown before, but which previously existed. When by induction or experiment we arrive at the knowledge of a new principle, we call it a discovery in science; and when we render discoveries or first principles of this kind subservient by means of their application to some useful purpose in art, we do so by what are

called Inventions. Science may therefore be designated a knowledge of the laws of nature already in existence; and invention, on the other hand, may be considered as applied science, by which certain fixed principles are established for our guidance in constructive art.

The solar system, in which the sun and planets revolve, indicate natural laws which admit of no change, and which may be accepted as first principles. Such laws as those of density, force, and gravitation—the latter first discovered by Newton—were founded by the Great Author of Nature, and have been made known to us through the labours of both ancient and modern philosophers. It is not, however, my intention to discourse on the motions of the planets, nor of those vast systems which comprise the fixed stars, and other astronomical phenomena. On the contrary, I wish to consider the laws of terrestrial rather than of celestial objects, and to point out the great benefits we derive from the cultivation of science, and the application of its principles to the purposes of constructive art. Let me therefore solicit your attention, whilst I endeavour to point out the intimate and indissoluble connection which exists between first principles and the whole range of practical operations by which—to use the words of Scripture—'we live and move and have our being.'

It would be a vain and fruitless attempt to offer an opinion on all those numerous branches of science which have contributed to human progress. It will probably be more to your advantage that I should confine my observations to one or two departments, to show to what extent scientific knowledge, judiciously and properly applied, has of late years worked such wonders by increasing the comforts and enjoyments of life. Let us therefore consider—

1st. Steam, as the motive power in practical mechanics.
2nd. Railways.
3rd. Navigation; and
Lastly, Manufactures.

1*st*. *Steum*.—According to this arrangement, we shall have to consider steam in the shape of water converted into an elastic fluid by heat. It may also be necessary to examine its properties as regards volume, pressure, and density, and ultimately to consider its application to the steam-engine, which we find equally beneficial, whether employed for the purposes of navigation, the transit of railway-trains, or as a prime mover in manufactories. In all these operations it is our faithful friend and slave, working continuously with a never-tiring and never-failing energy.

Steam, like most other vapours, is derived from the water that produces it. When water attains a temperature of 212° Fahr. under ordinary atmospheric pressure, it boils, and steam is given off. Steam, when slowly formed, contains about 966 units of latent heat, or heat not indicated by the thermometer. If to this be added 212° of sensible heat—the temperature of boiling-water—we have 1146·6 units of heat required to raise a pound of water into steam at 212°. So long as the water remains in an open vessel its temperature will not rise above 212°; but if the vessel be closed and the pressure increased, then the temperature will increase also. Bearing these facts in mind, we arrive at certain fixed laws which we have no power to alter, and to which we must adhere in the application of this important agent as a prime mover.

In the first place then we have water, which we know passes into steam under atmospheric pressure at the temperature of 212°, heat being lost during the change. The temperature of ebullition remains constant under the

same pressure, and we cannot increase it in an open vessel by an increase of heat, or by making a larger fire under it. Let us however close the top of the vessel and convert it into a steam-boiler, and we find the conditions entirely changed, but still subject to fixed laws, which regulate the progressive increase of the pressure, density, and temperature. Under these conditions there is a constant relation between the pressure and the temperature of saturated steam. The ordinary pressure of the atmosphere is 14·7 lbs. per square inch, and under this pressure we have seen that water boils and produces steam at a temperature of 212°. But at a pressure of 25 lbs. the boiling-point rises to 240°; at 50 lbs. pressure the temperature of ebullition is 281°, and at 100 lbs. it is 327½°. Hence we see that the boiling-point increases in a consecutive ratio with the pressure; and, moreover, the density of the steam also increases with the temperature and pressure. In my own experiments I have found that one cubic inch of water produces 1,641½ cubic inches of steam at the pressure of the atmosphere. But at 25 lbs. pressure it is restricted to 985 cubic inches, at 50 lbs. pressure to 508 cubic inches, and at 100 lbs. pressure to 268 cubic inches. Hence it will be seen that the density has increased in a similar ratio with the decrease of volume and the increase of the temperature and pressure. Again, it has been found that the latent heat of steam decreases, and the sensible or total heat increases, with the increase of pressure. The discovery of this law we owe to the experimental researches of M. Regnault. Moreover, from experiments with steam when isolated, and the application of heat continued, certain results have been obtained. My own experiments, and those of Mr. Tate, show that it obeys the same law as a perfect gas, increasing in volume and temperature at the same rate as atmospheric air, and is therefore known as superheated steam.

In this state it has become general in its application to the steam-engine. The practice of superheating is now generally adopted, especially in steam-vessels where the economy of fuel is a consideration of great importance. It has been understood, although imperfectly, that the expansion of superheated steam follows the same law as air, or any other perfect gas; that is, when the steam is not in a saturated but in a dry state, it obeys the same law of expansion as common air when heated to the same degree of temperature. Now, as some uncertainty was entertained on this question, I undertook, conjointly with Mr. Tate, to solve the difficulty by a series of carefully-conducted experiments, to verify this law of expansion, indicated by our previous investigations on density, volume, and pressure, to which I have directed your attention.* The results of these experiments may be stated as follows:—

The earliest experiments on the expansion of superheated steam of which we have any account were made by Mr. Frost in America, but without sufficient accuracy to be of scientific value. Mr. Siemens has also experimented on the expansion of steam isolated from water; his results give a much higher rate of expansion for steam than for ordinary gases; but, owing to the obvious defects of Mr. Siemens' method of conducting the experiments, it was considered by himself that the results were not reliable.

For gases, the rate of expansion is expressed by the formula, for constant volume—

$$\frac{P}{P_1}=\frac{E+t}{E+t_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where E is a constant derived from experiment, and determined by Regnault to be 459 in the case of air. In the

* For the experimental researches on the density of steam at different temperatures, and to determine the laws of superheated steam, vide *Philosophical Transactions*, 1860, p. 185.

paper alluded to it was shown that, with a certain proviso, the rate of expansion of superheated steam nearly coincided with that of air. Within a short distance of the maximum temperature of saturation, the rate of expansion of steam was found to be exceedingly variable; near the saturation-point it is higher than that of air, and it decreases, as the temperature is increased, until it becomes nearly identical with that of air. The results on which this law was based were too limited in their range for much numerical accuracy in the constants deduced.

Hence it has since been our object to supply this deficiency, by affording experimental data of the expansion of steam at higher temperatures and with a greater range of superheating than was possible with the apparatus employed in ascertaining the density of steam. The results obtained in these later researches, however, confirm the general law deduced from the previous ones.

It will not be necessary in this place to give the details of the experiments, nor to furnish descriptions and drawings of the apparatus from which the results were obtained. Suffice it to observe that they were conducted with extreme accuracy, and the results were confirmatory of M. Regnault's law, derived from the pressure of the vapour of mercury, with which that eminent philosopher kindly supplied me from his unpublished experiments. The results are therefore confirmatory, and almost in perfect accordance with, Regnault's investigations and the calculations of Rankine, as will be seen from the following summary:—

Summary of Results.

The law of expansion of gaseous bodies is expressed by the formula—

$$\frac{E+t}{E+t_1}=\frac{PV}{P_1V_1}$$

$$\therefore \ \text{E} = \frac{\text{P V} t_1 - \text{P}_1 \text{V}_1 t}{\text{P}_1 \text{V}_1 - \text{P V}}$$

where E is a constant. The values of E thus deduced are placed in order in the following Table. They show a decreasing rate of expansion from the saturation-point upwards until (at a certain increase of temperature) the rate of expansion coincides with that of a perfect gas.

Taking from the preceding Tables the two results, which in each case represent the rate of expansion at the greatest distance from the saturation-point, we have the following values of E:—

(1)	474·48
	450·11
(2)	455·57
	443·86
(3)	466·85
	451·94
(4)	464·83
	460·79
(5)	460·28
	9)4128·71
Mean value of E	= 458·74

The value of E for air, as ascertained by Regnault, is 459; that assumed for a perfect gas by Rankine is 461·2.

Hence the conclusion which we suggested in a previous paper (before alluded to) has been satisfactorily determined in more carefully-conducted experiments, and the rate of expansion of superheated steam is shown to be almost identical with that of air and other permanent gases, if calculated at temperatures not too close to the maximum temperature of saturation.

These are the laws which indicate the properties and govern the action of steam, and to which we must

adhere, if we wish to avoid dangers and mistakes in its application to the purposes of engineering practice. As an example to show its effects, let us take the case of a locomotive engine working at a pressure of 150 lbs. per square inch; and we find that the cubic contents of the boiler, after deducting that of the tube, is equal to 140 cubic feet; three-fourths of this space contains water, and the remainder steam. Small as this vessel may appear, it resists on its interior surface, at the working pressure of 150 lbs. on the square inch, a force, tending to burst it, of 15,000 tons; and the steam, when permitted to enter the cylinders, will cause the engine to exert a force equivalent to 700 horses' power moving at a velocity of 50 miles an hour.

Having stated thus much with regard to the properties of steam, let us now consider the principle on which it should be produced, and how it should be used with economy and safety. For a long series of years this has been a desideratum anxiously sought for, and although we have not as yet fulfilled all the conditions required for the attainment of that object, we have nevertheless made great advances in the procuration and use of steam. In the earlier stages of the steam-engine there were no vessels capable of generating steam at a higher pressure than from 7 to 10 lbs. upon the square inch, and for many years engines were never worked above that pressure, if we except the pumping-engines of Cornwall, which were worked expansively (as early as the beginning of the present century) with steam from 20 to 30 lbs. on the square inch, obtained from cylindrical boilers. This state of things continued till 1840, when the use of high-pressure steam was urged on public attention by myself and others as a source of economy, which required at that time, as well as now, the most attentive consideration. In the same year the double-flued boiler was introduced, in which

high-pressure steam was generated, and worked expansively, and this principle has been continued in nearly all the engines that have been made since that time. Many of the low-pressure engines have also been altered and strengthened, so as to cut off the steam at one-half and, in some cases, two-thirds of the stroke. By these improvements a great saving of fuel has been effected; but, unfortunately, they have been attended with serious disasters and loss of life, by attempts to work the low-pressure boilers up to a standard beyond their powers of resistance. These catastrophes became so frequent as to cause the organisation of the Association for the Prevention of Boiler Explosions, which for the last ten years has not only saved a large number of lives, and property of considerable value; but its careful periodical inspections, improvements, and recommendations have rendered the working of the steam-engine expansively, with steam at 40, 60, and 70 lbs. per square inch, comparatively safe. Under the auspices of this association, and others which may be formed on the same basis, increased pressure and economy may be looked for, and the manufacturing public and steam-users of every class may reasonably anticipate the greatest benefits from their labours.

Having thus shown what applied science has done for the steam-engine in a chemical and mechanical point of view, it may not be uninteresting, before closing this part of the subject, to glance at what has been the result of the same principles applied to locomotion. It must be borne in mind that steam-power, as an agent for the traction of carriages, did not escape the penetrating genius of Watt; and Murdoch, before the beginning of the present century, made a model engine, which I saw at work on a circular railway at his own house in 1828. This was probably the first attempt at locomotion by means of steam. But we may safely pass over the improvements which followed, from that

time, until we come to the competition at Rainhill, when the whole of them were developed, a few weeks previous to the opening of the Manchester and Liverpool Railway, in 1830. These improvements were variously conducted by Trevithick, Blenkinsop, Hawkworth, Foster, Dodd, and Stephenson; but the crowning effort took place as stated in 1830, and the result was the splendid achievements we have described in another place, and to which I shall have to refer when we come to treat of Railways. Suffice it for the present to state, that previous to the competition at Rainhill, there were no attempts to run locomotive engines more than ten miles an hour; and, in fact, there was no chance of increased speed, as the great drawbacks were defective boilers and a deficiency of steam.

To remedy these defects the heating surface of the boiler was augmented, and the exhaust-steam was thrown into the chimney, whether by accident or design is not exactly known.* At all events considerable improvements were effected by both, but still insufficient to supply the necessary quantity of steam for high speeds—which, by-the-bye, were never contemplated—till the generative powers of the boiler were proved to be inadequate at Rainhill. Mr. Henry Booth, however, recommended the small tubes to Mr. Stephenson, which gave the required heating surface for the supply of steam, and the victory to the 'Rocket.' This principle of diffusion and increase of surface gave the finish to the locomotive engine, and from that time to the present may be dated all the improvements and all the wonderful results which are daily witnessed in the economy, speed, and enormous traffic of the railway system.

Improvements, to meet certain conditions, have been

* Mr. Stephenson stated to the Author that he introduced it into the chimney not from a previous knowledge of its properties as a blast, but to get quit of the nuisance.

made in America and the Continent of Europe; but they are entirely local, and do not affect the general principle first introduced into the locomotives of this country. The French and German engines are identical in principle with our own, but are slightly varied in construction. The American engines exhibit greater difference in form, but, notwithstanding the numerous attempts that have been made and the amount of talent that has been brought to bear upon the subject, there has been no improvement upon the principle first developed in the 'Rocket' at Rainhill. The increased heating surface introduced into the boiler by numerous small tubes and the injection of the blast into the chimney has, however, given the finish to the engine as it now exists. These two appliances constitute the principle and efficiency of the locomotive engine, and, like the separate condensers of Watt, seem to have set at rest every other attempt at improvement. Much has been done and more may yet be accomplished in the form and working details of the parts, as may be seen in the American engines with bogie-carriages in front, adapted to turn round sharp curves, and the cow-catcher and spark-catcher where the line is not fenced, and where wood is used for fuel.

All these improvements and adaptations are intended to meet certain local requirements, and the Americans have availed themselves of constructions suited to wooden rails with thin iron bars nailed to the surface in the first instance, and the inverted cone covered with iron wire-gauze as a spark-catcher in the second. These contrivances to meet certain local conditions, although not leading to any new discovery, are nevertheless highly beneficial to the community, and this aptitude of adaptation is a striking proof of the advantages of applied science and the development of industrial resources.

2*nd*. *Railways*.—If we revert to the means of transit

as it existed before the introduction of railways, we shall find an extraordinary development of a system that has changed and is now changing the relations of all countries, as regards the means not only by which we are transported at the speed of the racehorse from one end of the kingdom to the other, but the effects which these changes produce in the social relations of individual communities and the intercourse of nations. If we consider the rapidity with which that intercourse is effected, and the comparatively small rate of charge by which we are carried great distances, we at once come to the conclusion that we live in a new era of the world's history, and, moreover, that we enjoy facilities of intercourse unknown to the past, and such as must prove advantageous to the future. These changes in our social condition become the more prominent when we reflect on the days of the pack-horse, the waggon, and the stage-coach. All these modes of conveyance have terminated, and are now entombed in the history of the past. In fact, the slow pace of three to nine miles an hour is superseded by the magic flight of the locomotive train—with its human cargo—which sweeps over the face of the country, in every direction, at the rate of fifty miles an hour. These wonderful achievements may be measured by a period which dates from 1830; and supposing the principles of high speeds to have been realised in 1840, we then arrive at the fact that ten years was only required for the development of this wonderful and very important system.

It may be interesting to enquire, now we are in the midst of railways, what effects they have produced upon society; and these being taken in connection with other improvements consequent upon their introduction, we arrive at the conclusion that the moral and physical conditions of the great mass of the community are greatly improved. If in illustration of this statement, we compare the condition

of the population at the commencement of this century with what it is at present, we shall be convinced of its accuracy. If, for example, we examine the state of society as it existed sixty years ago, when a working mechanic had from 20*s*. to 24*s*. per week, day-labourers in towns from 10*s*. to 12*s*., and agricultural labourers from 8*s*. to 10*s*., we come to the conclusion that the working-man is better off now than then, and that the rate of progress has not deteriorated but improved the condition of all classes. The above may be considered the approximate rates of wages at that time: now they are nearly double in the case of mechanics, and there has been a proportional increase of 20 to 25 and 50 per cent. in that of town and country labourers.

The middle and upper classes have probably been benefitedin a greater degree than the labouring class, as the amount of business done in the country has more than doubled, and every description of property has increased in value in similar proportions. But this is not all, as the price of provisions—with the exception of butcher's meat—has not increased in a corresponding ratio, and in articles of clothing a great and important saving has been effected. Altogether, therefore, the present generation are much better off than that of fifty years ago, and no small share of this important change is attributable to the introduction of railways.

It is not, however, exclusively to railways that we have to look for the improved condition of the population. Other discoveries in practical science have contributed largely to this result, and we may instance those of a physical and chemical nature which have brought to light the proper diffusion of heat, the economy of fuel, and the principle of Dr. Joule's equivalent, which enables us to calculate the amount of work done by any description of elementary force generated by the introduction of heat. Let us briefly examine some of those discoveries applicable

to the steam-engine and the locomotive, and we find that a more perfect knowledge of physical laws, when practically applied, has led to a saving of one-half the quantity of fuel in the steam-engine to what it required twenty years ago: or, in other words, one pound of coal rightly applied will do double the work it was able to accomplish before the improved principle was introduced.

In the pursuit of practical science the great and important features of the present age are experimental inquiry and inductive reasoning. The principle of theorising is out of fashion, and nothing is taken for granted in scientific investigation, but proved by the test of actual experiment. With all due respect to our friends and coadjutors in the higher branches of mathematics who are so well known, and to whom we are indebted for theoretical formulæ, I am of opinion that the calculations in practical science are more certain when the formulæ on which they are founded are deduced from actual experiment. To prove this, many examples may be given to show that experiment is the only true exponent of physical laws which relate to practical science, and the formulæ deduced therefrom are the standard rules by which those laws in all their varied forms can be safely applied. There can be no greater proof of the union of science and constructive art than applied mathematics, as a knowledge of first principles can only be attained through the aid of the mathematician. For example, in Dr. Joule's equivalent, he proves, by experiment, that heat and force are reciprocally convertible, and shows distinctly that we cannot apply heat to any body without creating its equivalent of force, and, *vice versâ*, we cannot apply force without generating its equivalent of heat. If, for example, a body is compressed by a force of 1000 lbs., heat will be generated or given out as the equivalent of that force; and by reversing the motion or removing the force, and allowing the body to

cool, it follows that the heat lost in returning to its former state is in proportion to the force originally applied. Hence Joule's law is, that the introduction of as much heat as will raise a pound of water one degree, is the equivalent of 762 lbs. raised to a height of one foot. It is from these and other discoveries, such as working high-pressure steam expansively, increasing the speed of our engines, and other practical improvements, that we have been enabled to economise our fuel to the extent of performing double the quantity of work.

Before closing this part of our subject, it may be interesting still further to show what effects railways have had upon the political changes of countries embroiled in war. This is a question that has partly been solved in the recent contest between the late Federal and Confederate States of America.

In a country intersected by railways, it is important that an army acting on the defensive should keep open the line between its existing position and its base of operations, and that supplies of ammunition and all other requisites of the Commissariat should be expeditiously and safely supplied. When this can be done by rail, an immense saving of time and money is the result, and this may be greatly augmented by the expeditious transit of troops and the materials of war. This was clearly shown in the late contest in America, and the retention of an open railway, to one or other of the belligerents, not unfrequently decided the victory. Large armies composed of cavalry, artillery, and all the accessories of equipage, ammunition, &c., could not be transported from place to place with any degree of certainty, unless preparation and previous arrangements were effected; and even then it could not well be done for short distances, but in long journeys much time may be saved and great results accomplished by the transport of troops and reinforcements by rail.

It is for the continental nations of Europe to decide this question, as they are more exposed to invasion than the inhabitants of this insular country; and I apprehend it must be left to the military authorities to determine the means to be adopted in order to meet all the arrangements of military transport. To surmount the difficulties to be overcome in the transport of infantry, cavalry, and artillery, we should have to put railways under military training, and this could only be done in cases where lines of railways existed between the different depôts and the seat of war. In this case railways would be useful for whichever of the contending armies could keep possession of them. Let us hope that in this country they may never be wanted for such a purpose, and that we may continue to enjoy rapid transit free from the pageantry and pomp of war.

3rd. Steam Navigation.—It must be acknowledged that the discoveries in science and their application to the purposes of civilization have changed the mutual relations of countries. The luxuries of former days have become the necessities of the present, and we have many blessings and many enjoyments for which to be thankful. We are better housed, better clad, and better fed than at any previous epoch, and we owe many of these comforts to steam-navigation. It is little more than half a century since the first steamboats floated on the surface of the Hudson and the Clyde. To this branch of applied science great attention has been paid, and the result is before us on every sea and in every part of the globe. The earliest experiments of importance in steam-navigation appear to have been those of Mr. Miller. In 1788 he built a vessel with paddlewheels, which was tried on the loch of Dalswinton, which gave good results. This was followed by the construction of another vessel with a steam-engine, built by Mr. Symington; and in 1801, with the aid of Mr. Symington, Lord Dundas built a vessel of considerable power, which

was employed on the Forth and Clyde Canal. Fulton, after unsuccessful experiments in France, went to Scotland, and made a trip in the 'Lord Dundas,' the details of which he carried with him to America, and the knowledge thus acquired he afterwards applied in the construction of steamboats on the Hudson.

The United States were not behind, if they did not take the lead,in shipbuilding and steam-navigation. The Americans, however, were not the first to apply the steam-engine to navigation, but the first to render it practically useful, although very closely followed by this and other countries. It was in 1807 that Fulton opened a steam-communication on the Hudson between New York and Albany; and in 1811, Henry Bell, of Glasgow, made his first trip with the 'Comet' on the Clyde. We are all acquainted with the progress made since that time, and the science and skill by which the present high degree of perfection has been attained.

For more than twenty years the steam-engine applied to paddlewheels was the only means of propulsion, but about 1830 Mr. Bennet Woodcroft showed me a plan he had invented for propelling vessels by means of a screw. It was not, however, till 1837 that the merits of the screw were fairly tested in the experiments of Captain Ericsson and Mr. F. P. Smith. In that year Captain Ericsson's small vessel, only 45 feet in length, towed the Admiralty barge from Somerset House to Blackwall and back, at the rate of ten miles an hour. In 1839 the 'Robert Stockton' was built on the same principle, and in 1840 the 'Archimedes' made its appearance on the Thames, after which the Admiralty introduced the invention into the Navy, where it has entirely superseded all other means of steam propulsion. It is not, however, for ships of war alone that the screw has been employed. On the contrary, it is applicable to every description of vessel, and is now

extensively used not only as an independent instrument of propulsion, but also as an auxiliary to assist vessels under canvas, and to shorten the voyage in head-winds or profound calms.

At the first introduction of the screw-propeller, toothed wheels were used to obtain the velocity proportionate to the diameter of the screw and the required speed of the vessel. Since then it was found more economical and much more advantageous to work the screw-shaft direct from the steam-cylinders, with short strokes corresponding with the velocity required for the screw. Dispensing with the cogwheels was a great improvement, not only for the purpose of bringing the power of the engines direct upon the resistance, but for simplifying the parts in motion, and rendering the engine a less complicated machine, and more compact in form than it was with the speed-wheels and the long stroke. In ships of war this improvement had another advantage—that of keeping the whole of the machinery low in the ship; and by fixing the cylinders horizontally on their sides, the whole of the working parts were placed out of harm's way under the water-line.

In merchant-vessels the screw-propeller is worked in a variety of forms—by placing the engine vertical, oblique, or at different angles with the horizon. Other improvements have been introduced, by fixing a screw at the stern on each side of the ship's quarter. This was the original plan, adopted by Ericsson and others; but certain improvements and modifications, introduced by the late Mr. Roberts, have changed that scheme so as to render the double screws applicable not only as propellers, but by separate engines enabling them to revolve in opposite directions, the vessel may be turned round in a circle of a radius not exceeding half or three-fourths of the length of the ship.

For the purpose of manœuvring, the double engines

perform an important duty in rounding the ship; and now that heavy guns constitute the armament of the Navy, it is a desideratum in naval warfare that they should be worked with facility and despatch, either by the quick movements of the vessel, or on Captain Cowper Coles' principle of revolving turrets. It is not yet ascertained which of the two systems is the best; but it appears quite evident that the ship must either have the power to effect a change of position with celerity in action, or the guns must revolve on turret-tables in order to bring them to bear upon the enemy with efficiency. There may be some objection to Captain Coles' principle of working the guns, on account of the confined state of the interior of the turrets, and the want of adequate ventilation, but probably ways and means may be devised to surmount these difficulties.

I cannot close this subject without adverting to another branch of practical science, which originated in the researches and discoveries of Captain Maury, as given in his able work 'On the Physical Geography of the Sea.' To that gentleman's labours we are indebted for many benefits conferred on navigation. It may be said of Captain Maury that he has analysed the bed of the Atlantic Ocean, noted its currents, and ascertained the direction of its prevalent winds. He has, moreover, shown to us the direct way to India, Australia, and our Colonial possessions in all parts of the Pacific and the Indian seas; and he alone has saved, by his discoveries and instructions, to this country, sums that may be counted by hundreds of thousands per annum. These are his achievements in the field of applied science: his charts and sailing directions deserve the gratitude of the world; whilst the immense number of lives and the vast amount of property his labours have saved are the best and most enduring monuments of his genius.

From this sketch of the progress of steam-navigation, it will be seen that applied science has been a great benefactor to our social relations afloat as well as on shore. By its aid we have overcome the difficulties of wind and tide, and doubled or even trebled the speed of our vessels. We have also attained certainty and despatch in postal communications with other countries, and I am satisfied that science and its application to the wants and necessities of everyday life is the only true and effective system of progress.

Lastly, *Manufactures.*—Let us take Cotton for instance —one of the largest and most important staple articles of manufacture in this country—and we shall find that in all the multifarious processes to which it is subjected, scientific principles have been applied with results as remarkable as in any of the examples we have quoted. How effective and ingenious is the machinery by which the raw cotton is converted into yarn, and with what exactitude it performs the various duties of blowing, carding, drawing, and roving, until at last the operations terminate in the production of threads as fine as gossamer, and of length sufficient to girdle the world a thousand times in a single hour! In the blowing-machine we have the beater, the fan, and the delivery-rolls, as in the thrashing-machine invented by Andrew Mickle, from which it has been derived. In the carding, drawing, and roving machines we have the results of the fruitful minds of Arkwright and others, with the differential motion of the roving-frame and its more modern improvement. From these we pass to the mule and throstle frame, the former taking its name from Compton's combination of the spinning-jenny and the throstle, and the latter from the warbling noise of the spindles—which is, however, much less musical to some ears than that of the bird to which it owes its title. Now all these machines, though so familiar to us of this district,

are nevertheless wonderful examples of applied science. Probably the inventors themselves were not aware that their ingenious contrivances were founded on strictly scientific principles; yet no one can witness these processes without being convinced that such is the fact; and, moreover, that we are indebted for the combination, beauty, and exactitude of the operations of these intricate machines to the ingenuity of the inventors.

One of the most remarkable applications of recent date is Signor Bonelli's invention of the electro-weaving machine, which performs the office both of selecting the threads and lifting the healds as in the jacquard-loom. The system of perforated cards, hitherto universally employed in figure-weaving, is attended with great expense; the cards are cumbrous, and require the utmost care on the part of the weaver. But by the electric process of Signor Bonelli these cards would be entirely dispensed with, and the division of the warp and all the complicated movements of the machine would be effected by the aid of electric currents, transmitted through a series of plates in contact with a metallic cloth on which the pattern is drawn. These again, acting through a series of electro-magnets, give motion to the healds. The magnets are as many in number as the threads to be lifted, and on the transmission of a current through the metallic cloth they give motion to the needles, which have power to raise the thread of the warp, but the power of selection is such as to raise only those which must be lifted to produce the figure. And in this there could not possibly be a more ingenious contrivance, as the figured pattern-cloth, by transmitting a current through those parts only on which a pattern is not drawn, gives motion to the needles in combination with the threads of the warp. The plates that traverse a part of the cloth on which the pattern is drawn with a nonconducting varnish, transmit no current, and the

needles in connection with them remain quiescent. From this description it will be seen that any figure, however complicated, can be produced without the aid of cards, by a contrivance which is perfectly automatic or self-acting, so as to relieve the weaver of any mental labour, as respects the working of the healds and the production of a perfect facsimile of the figure imprinted on the metallic cloth. I believe M. Bonelli has contributed, on the same principle, an entirely new system for the transmission of messages by telegraph, by means of which a perfect facsimile of the letter written at one place is transferred to the other. I have not, however, witnessed the operation of this system, and cannot therefore offer any opinion as to its practicability.

Another important addition to applied science is the pneumatic loom, the invention of Mr. C. W. Harrison, in which the operation of projecting the shuttle through the shed of the warp is effected by reciprocating jets of compressed air, communicated by pipes to the shuttle-boxes of each loom. Exceedingly small valves are attached at each end of the beam, and these are worked by the oscillating motion as it moves backwards and forwards to beat up the weft. This new and improved system of loom has not as yet been fully developed, nor has it come into general use. It has, however, many important features to recommend it—such as the saving of power, the softness of the motion as the shuttle leaves and enters the boxes on each side, and the uniformity of pressure by which it is projected across the shed. Again, it has the advantage of dispensing with the jarring noise of the picker, and a system of cases which, working at high velocities, are always objectionable. These appear to be the leading features of the invention; but, notwithstanding its apparent advantages over the powerlooms now in use, there may be some drawbacks with which I am not acquainted.

The ground on which this opinion is based is, that it has not made that progress in public estimation which was at first anticipated. Let us however hope, whatever defects may exist, they may be remedied, and that the pneumatic loom may be classed amongst useful inventions as another valuable contribution to practical science.

Before noticing the processes of bleaching and dyeing, I would for a moment refer to the combing-machine, as another instance of the application of mechanical science in preparing the finer descriptions of cotton. This machine is of French origin and of recent date. It is a combination of mechanism to effect the arrangement of the cotton fibres by a combing process, to enable each fibre to slide past the others, and effect without twist the operation of removing the entangled mass. The necessary twist is afterwards given by the roving-machine; but, speaking under correction, the first object to be attained is to secure the parallelism of the fibres, so that the succeeding processes of drawing may be effected with greater ease. The combing and carding machines are admirably adapted for this purpose, and the only advantage of the former is its greater adaptation to the finer descriptions of yarn. In weaving there are numerous examples of ingenuity and skill in mechanical appliances, besides the jacquard and electric looms, to which I have already adverted. Of these I shall only refer to the stocking-loom, perfected after years of labour, difficulty, and suffering by its ingenious author. There is a little history connected with this invention, not only interesting in itself, but highly instructive to those who would imitate the labour and tread in the steps of its illustrious contriver. But the story is so well known that I need not repeat it here.

In the application of chemistry, a wide field of research is open to those who have made themselves familiar with the laws of combination and the products of the laboratory.

To this science we owe the extraordinary results which have been achieved in the processes of dyeing, bleaching, and printing. Of these the most remarkable of recent times has been the production of red, purple, and violet dyes from aniline, a substance obtained by the distillation of coal-tar. Photography is another signal illustration of the advantages of the same science; and a new era in the manufacture of iron is bursting upon us as the result of the prosecution of mechanical and chemical research in that department. Looking at these facts, I think you will agree with me that the subject is well worthy of consideration, and ought to form part of the studies of young men in every grade of life.

I have alluded to these facts to impress upon you, and on the members of kindred institutions, the importance of scientific knowledge, and to show that there is no trade, however humble, which is not dependent on scientific knowledge. I have attempted to show the importance of physical science when practically applied, and how unsatisfactory are the results when the combination of first principles have been neglected. Ignorance on these points are sure to lead to failure: so that, in order to fulfil the duties we are called upon to execute for ourselves and others, we must work in intelligent subservience to those unerring laws, by which we shall be led to discoveries and inventions in the constantly-extending fields of scientific research and constructive art.

LECTURE II.

ON THE PRESENT STATE OF PROGRESS IN SCIENCE AND ART.

If we consider the present state of our knowledge, and compare it with what it was half a century ago, we shall have reason to congratulate ourselves on the position we now occupy. Our rate of progress, and the advantages we derive from the improved condition in which we are placed, is obvious, either as regards our moral or intellectual culture. The last fifty years have been remarkable for discoveries, inventions, and improvements in every branch of science; and if we are to calculate our future advancement at the same rate of progress, we shall arrive at a period when the march of civilization and the spread of intelligence will penetrate the homes and heads—I hope also the hearts—of every member of the community. I do not expect that our successors will be all learned men and women any more than ourselves, but I have reason to believe that the next fifty years will witness a generation of men of increased mental acquirements, and of a much higher standard of character than the present.

It doubtless requires a more acute discernment than that of the human mind to penetrate the future and picture coming events; but, assuming that no material change and no serious interruption take place in the condition of the inhabitants of this country, we may safely conclude that a new and greatly-advanced period is in progress, far

exceeding that which now exists, and probably more in unison with a higher standard of mental improvement. Let us suppose that such a state of things will continue, and we shall find we are not too sanguine in predicting that a happier and more intelligent race of men will take the place we now occupy, and thus, by continued improvement, lead to a higher and more intellectual state of existence.

That such results are likely to follow our present system of mental acquirements is more than probable; and looking forward to its approach, I have not hesitated to lend my humble aid to this and other institutions in encouraging the onward progress of education, and in bringing it to bear upon every class of the community.

If we examine ourselves, and look carefully into the history of individuals, we shall find, in this struggle of life, much to learn, much to approve, and much to avoid. The longest life is comparatively short; time is therefore of great importance, and we cannot too often employ it in the acquisition of knowledge. There is nothing that requires more management than the proper distribution of time, and its application to useful and judicious employment. To those engaged in the pursuit of knowledge it is of paramount importance. In youth, and in some instances in mature age, we are entirely regardless of its value; but when viewed as the measure of life, we become sensible of its importance, and regard its proper appropriation as a question of serious import in every pursuit and in every condition of existence. On many occasions it is wasted in idleness and unsubstantial pleasures, and we too often forget its rapid flight until we arrive at that period of life which convinces us that it has disappeared without the concurrent reflection that it has been well spent. Happy indeed is the man who can look back on the past with the conviction that he has ad-

vanced in knowledge and virtue, and that his time has been judiciously and usefully employed!

In the retrospect of life there are few of us that can pass in review the years that are gone without a sense of humiliation and regret; for we all remember many shortcomings and many follies in our past career. He is, indeed, a fortunate man who can say that he has improved in wisdom, and left nothing undone that he ought to have done to render his time valuable. And yet there is something in the reflection, that most of us would like to repeat not only the virtues but some of the follies of youth. In fact, there is more in this than most people are willing to admit, and I for one believe that the errors of life are not unfrequently the precursors of honour and virtue, and ultimately become instructive lessons for our future guidance. Assuming this to be the case, and knowing from our past lives that we have neglected too frequently every school but that of experience, we then arrive at the conclusion that the deviations from a straightforward course are not altogether without their use, in proving what we have to learn and what it is necessary we should avoid.

A celebrated writer states—'that in reviewing past life many things now appear of inconsiderable importance which once occupied and attached to us in the highest degree. Where,' he observes, 'are those keen competitions, those mortifying disappointments, those violent enmities, those eager pursuits that we once thought were to last for ever, and on which we considered our whole happiness or misery as suspended? We look back upon them now as upon a dream which has passed away. None of those mighty consequences have followed that we had predicted. The airy fabric has vanished, and left no trace behind it. We smile at our former violence, and wonder how such things could ever have appeared so significant and great.'

These and many other considerations of a similar kind are the reminiscences of the past, which we have to look back upon in the retrospect of life, and it not unfrequently happens to be accompanied with some measure of self-condemnation and regret. Even the most pleasing scenes, and the joys that are past, are attended with regrets and secret sorrow. The pleasurable scenes of youth, the objects on which our affections have been early placed, the companions and friends with whom we have spent many happy days, can hardly ever be recalled without the conviction that the regrets and consolations of the past are not unfrequently in close alliance with the thoughts and actions of the future. These sensations are familiar to every one of us, and it is one of the consolatory reflections of old age, to return to the pleasurable scenes of early life, to criticise the cares and contests in which we were engaged, and to 'shoulder our crutch and show how fields were won.' But I am wandering from the more direct object of inquiry, and that is, the present state of our knowledge in science and art as compared with the past. Now, this is a subject which requires careful handling, and would, I doubt not, have been more clearly and distinctly rendered if entrusted to abler hands and wiser heads than my own. I must however trust to my past labours, and the experience I have acquired as a worker in the wide field of practical science, as my apology for venturing upon the consideration of this important question.

In our treatment of this subject, it will be necessary to show:—

1st. The state of our knowledge of science and art as it existed previous to the discoveries of Watt, Arkwright, and others.

2nd. Its progessive improvement; and

Lastly. Its comparative value and influence on society.

It must be known to most of us who have studied history, that during the time of the civil wars down to the reign of George II., the industrial resources of the country were at a very low ebb, and the applied sciences were seldom or never thought of: beyond that period, if we except Sir Isaac Newton and some other distinguished philosophers, there were very few workers in abstract science. The reign of George III. was more encouraging, as it gave birth to some of the greatest names in the pursuit of practical science that this country ever produced; and these may be enumerated by the inventions and labours of Watt, Arkwright, Crompton, and Wedgwood. To these men we are indebted for the steam-engine, the machinery for the spinning of cotton, and the improvements in the manufacture of porcelain, or that article which is better known by the name of Staffordshire-ware or pottery. Other branches of industry have made great progress, and in them may be enumerated the manufacture of iron as comprised in smelting, hammering, rolling, &c. All these are due to the labours of Cort, Neilson, Bessemer, &c.; and the improvements in the silk, flax, and woollen manufactures have grown out of the successive inventions in the machinery for carding, roving, and spinning cotton. To each of these we shall have occasion to advert, as we take them consecutively in order as follows:—

(1) ON THE STATE OF OUR KNOWLEDGE OF SCIENCE AND ART AS IT EXISTED PREVIOUS TO THE DISCOVERIES OF WATT, ARKWRIGHT, AND OTHERS.

We are not well informed on the state of science as applied to the useful arts during the remote periods of English history, nor have we any reliable facts relative to the commercial and manufacturing industry of the country during the feudal epoch, when war and pillage were in the

ascendant, and when the peaceful and industrial habits of the people were liable to be disturbed by the alternate and conflicting demands of war and labour, whenever it suited the chief to encourage the imposition of black-mail upon neighbouring estates. Under such a state of society, when both life and property were insecure, it would be impossible for the manufacturing industry to flourish, and we may reasonably suppose that it was at an exceedingly low ebb. It is recorded that woollen and iron manufactories were in existence during the days of the Tudor sovereigns down to the time of Queen Elizabeth ; but they could not have been able to meet the wants of the community of those days, as most of the working-classes and agricultural labourers wore leather jerkins, and the woollen cloths manufactured at that period consisted chiefly of coarse serges and a very indifferent description of blanket. The manufacture of iron was, however, in a more advanced state, as the country at that time was covered with wood; and charred wood being the only fuel used for the smelting and blooming processes, the ores of Sussex, Surrey, and the Forest of Dean were at that time in a comparatively flourishing state. This manufacture continued to improve until the forests were exhausted, when it was greatly reduced during the civil wars and the days of the Commonwealth—the whole amount of production being confined to 80 or 90 small furnaces, and a yield of about 18,000 to 20,000 tons per annum; now it is four millions.

During these primitive times much could not be expected from any improvements that might have taken place in the extension of manufacturing industry, as there were no roads and no means of transport, excepting that which was carried on the backs of horses. Even as late as Charles II.'s reign, most of the transit of goods was effected by the packhorse, and, with the exception of the metropolis and some of the large towns, there were

few if any carriages in existence. During the reign of Queen Anne, and from that time up to the commencement of the reign of George III., there only existed a few carts and waggons, and two or three stage-coaches travelling on bad roads between York and London, and between London and Bath. Most of the journeys of those days were undertaken on foot or on horseback, and the journey from Edinburgh to London, which now occupies eleven hours, took from a fortnight to three weeks for a well-mounted horseman to accomplish.

On this subject alone it is curious and interesting to trace the successive changes which have taken place, from the time when the whole transit of the country was carried on the backs of horses, at the rate of eighteen to twenty miles a day, to that of the locomotive which traverses the same distance in less than half an hour. The means of transit in those times may be compared with the present, as shown in the following statement, which exhibits the progress of science, and the improvements that have been effected during the successive periods to which we have referred.

It would appear that a horse will carry on his back about 333 lbs. a distance of eighteen miles in one day: and taking this as the basis of our calculation, I find the following comparisons of the past with the present to be pretty nearly correct, as respects the effective load moved by a horse in one day under the different mechanical arrangements to which his power is applied:——

ESTIMATE OF THE EFFECTIVE LOAD MOVED BY A HORSE OVER A GIVEN DISTANCE, IN ONE DAY, UNDER DIFFERENT SYSTEMS OF TRANSIT.

1. *A packhorse carrying a load on his back.*—A packhorse will carry 333 lbs. a distance of 18 miles in a day of 8 hours long—that is:

The effective load carried 18 miles = 333 lbs.

2. *A horse drawing a coach on the common road.*—A horse travelling at the rate of 10 miles per hour, exerts a tractive force sufficient to pull 850 lbs. effective load over the distance of 20 miles as a day's work.

Here the effective load for 20 miles = 850 lbs.

$\therefore$ " " 18 " $= \frac{850 \times 20}{18} = 944$ lbs.

It will be observed that this load is transported in one-fourth the time employed in the foregoing cases, *but the gain of time is attended with a loss of load.*

3. *A horse drawing a load in a cart on the common road.*—A horse, in this case, exerts a traction of 156 lbs. over the distance of 18 miles in a day of 8 hours long. The coefficient of friction being taken at $\frac{1}{16}$,

The effective load drawn 18 miles $= 156 \times 16 = 2{,}496$ lbs.

4. *A horse drawing a load on the railway.*—Assuming the same conditions as in No. 3, and taking the coefficient of friction on the rail to be $\frac{1}{280}$, or 8 lbs. per ton, we get—

The effective load drawn for 18 miles $= 156 \times 280 = 43{,}680$ lbs.

5. *A horse towing a load in a barge on a canal.*—A horse, in this case, can draw 44,800 lbs. 18 miles in one day of 8 hours long—that is:

The effective load drawn 18 miles = 44,800 lbs.

6. *Load due to a steam-horse.*—The load due to a steam-horse would be somewhat different. A steam-horse performs 33,000 units of work per minute.

$\therefore$ The work of a steam-horse in 8 hours $= 33{,}000 \times 60 \times 8$

The work of resistance over 18 miles $= \frac{W}{280} \times 5{,}280 \times 18$

$$\therefore \frac{W}{280} \times 5{,}280 \times 18 = 33{,}000 \times 60 \times 8$$

$$W = \frac{33{,}000 \times 60 \times 280 \times 8}{5{,}280 \times 18} = 46{,}666 \text{ lbs.}$$

—which is the effective load moved in this case.

Here it will be observed that the load moved increases with the time, or, in other words, it is inversely as the speed.

Summary of Results.

Taking the load transported by the packhorse as unity, we find the ratios of the loads transported by the different systems as follows:—

1. A packhorse with a load on his back	. 333 : 333, or as 1 :	1
2. A horse in a stage-coach on the common road	. 333 : 944, or 1 :	2·8
3. A horse in a waggon on the " "	. 333 : 2,496, or 1 :	7·5
4. A horse drawing a waggon on a railway	. 333 : 43,680, or 1 :	131·1
5. A horse towing a barge on a canal .	. 333 : 44,800, or 1 :	134·5
6. A steam-horse	. 333 : 46,666, or 1 :	140·1

We have, therefore, the following relative proportions of work done by a single horse under the different conditions in which his power is applied, as under:—

1. The packhorse	as represented by	1·0
2. The coach-horse	" "	2·8
3. The horse in a waggon,	"	7·5
4. The horse on a railway,	"	131·1
5. The horse on a canal,	"	134·5
6. The steam-horse,	"	140·1

These results are obtained on the supposition that the above ratios represent the utmost labour a horse can perform in one day in his differently-applied forms of transport.

For *low speeds*, $t = 250 - 41\frac{2}{3}\, r$, expresses the relation between t, the traction of a horse in lbs., and r, the rate in miles per hour at which the horse travels.

It results from this formula, that a horse performs the

greatest amount of work when he travels at the rate of three miles an hour, and with this speed he performs a standard unit of horse-power, or 33,000 units of work per minute.

In the foregoing calculation it will be observed that the maximum of work done by a single horse is in favour of towing a loaded boat at a slow speed on a canal, and the worst application of his power is when he carries the load on his back, being in the ratio of 1 : 134·5, as shown in the summary; or, in other words, he will accomplish 134½ times more useful work in a boat on a canal, than when the weight to be moved is laid on his back.

It must also be borne in mind that a locomotive goods-engine at 30 miles an hour exerts a force of 250 horses' power, and that each horse-power in a locomotive, when measured by time, will do ten times the work of an ordinary horse—which in the case of the stage-coach, when travelling at the rate of 10 miles per hour with a load of 850 lbs., is exhausted in one hour; whereas the locomotive horse is fresh at the end of 30 miles, and would go on continuously for a whole day of twenty hours with its energies unimpaired by time or distance. We have therefore, in reckoning by the day, to multiply the ratio of each locomotive horse-power, namely, 140 by 20 = 2,800, which raises the locomotive, in comparison with the packhorse, to 2,800 : 1 : and again, in the ratio of 2,800 : 134·5, or as 20·8 : 1 in the case of a horse towing the load on a canal. These are some of the changes and improvements of transit that have taken place during the last 150 years. But they by no means comprise the whole, as will be seen in treating of that part of the second division of our subject, which bears upon navigation and other advances in practical science.

(2) PROGRESSIVE IMPROVEMENT OF SCIENCE AND ART.

From the days of the Saxons and the invasion of the Danes down to the Norman Conquest we could scarcely be called a maritime people. A change, however, took place in the time of the Plantagenets, and during the period of the Stuarts the country made great progress in the construction of vessels, whether intended for war or commerce.* But the brightest era of our maritime prosperity was during the revolutionary wars with France, when the British navy cleared the sea of almost every hostile ship, and when the resolute and hardy seamen of our fleets were chiefly supplied from the North. The advantages gained in those days were not derivable from any superiority of our ships. On the contrary, we were behind both the French and the Americans, and our success was wholly attributable to the indomitable perseverance and courage of the officers and seamen of the fleet. As regards shipbuilding, we got our finest models from the French, and that important art was never at a lower ebb than during the French war. In the mercantile service the form of ships was even worse than those in the Navy, as the tonnage laws at that time were destruc-

* It may be interesting to notice the state of the Navy as it existed during the era of the Stuarts; and here it will be necessary to observe that during the Dutch wars, in which this country was engaged at that time, most of the battles were fought at sea. The Dutch were a powerful maritime state during the whole of Charles II.'s reign, and the equipment of fleets and other conditions consequent on these contests were of great value to the nation, and give it that ascendancy which it has ever since retained as the leading maritime power of the world. The Dutch wars of the sixteenth century, although expensive and often aggressive, were nevertheless of great value in directing the attention of the nation to the important advantages of cultivating that branch of the public service on which the security and influence of this country chiefly depend, and to which we may trace the advancement as well as the greatly-enlarged conditions of our present widespread and still-extending commerce.

tive of every attempt at improvement. Since the Peace of 1815 great changes and great improvements have been effected, and these may be traced to the introduction of steam. From that period, 1811, when Henry Bell made his first excursion with the 'Comet' on the Clyde, we may date all the improvements that have since taken place in the form of our ships, and the saving of time in the navigation of the seas. The old hulks, with bluff bows and quaint sterns, have given way to fine lines of entrance in front, so as to cut the water without a ripple, and a fine run behind to make her sensitive, and answer the helm with a facility never before attained. In fact, the vessels of the present day are what are called clippers, and, whether propelled by wind or steam, are of nearly double the speed of the old forms. These improvements have been effected by the application of science, the introduction of new principles in shipbuilding, and the results are increased speed and increased saving of money and time.

There cannot exist a doubt that the introduction of steam as a propelling power, and the consequent improvement of the forms of ships, have given a wonderful impetus to navigation, but the crowning-point was gained by the substitution of iron for wood in naval construction. This took place more than thirty years ago, and I believe I may venture to claim some credit, as one of the first that applied it on a large scale for seagoing vessels. Since then we have seen the satisfactory results which have already been obtained; and from what is now doing, and is likely to follow in the train of a new system of construction, both in the war and the mercantile navy, we may expect still greater advances. As respects the former class of vessels, we have only to witness the changes from wood to iron in the dockyards of every nation, to be convinced of its value, and to be assured of the estab-

lishment of a new era in the history of the war-marine of this and every other country. This revolution does not apply exclusively to iron as a substitute for wood in the construction of ships; but the sides of our vessels of war being encased in iron from five to six inches thick, both above and below the water-line, are rendered impregnable to the heaviest guns and shot now in use. To what extent the power of ordnance may yet be carried is not for me to determine; but guns, like ships, are progressing in about the same ratio, and probably the time is not far distant when we may calculate on the resistance of the armour-plate being equal to the force of the projectile. In this balance of force to resistance it will require larger guns, such as a 500 or 600lb. shot or shell, at a velocity of 1,400 or 1,500 feet per second, to penetrate at close quarters the thickest armour-plates, and lodge its contents in the interior of the ship.

It will be noticed, from what has been said, that improvements have been effected, and facilities afforded for the transit of passengers and goods, both by sea and land, greatly beyond the expectations of the most sanguine. But we may go further, and predict even more extended developments, till we arrive at the point when we may venture to think that the dreams of the 'Arabian Nights' are realised. The locomotive and the iron steamship have approached those imaginary flights, and he must be a bold man indeed who asserts that the human mind has reached the summit of its powers and can go no further. This is, however, fortunately not the case, as the principles of science are founded on natural laws, are still open for research, and I am fully persuaded we shall find them inexhaustible to the end of time.

Irrespective of what has been done for civilisation in the shape of rapid and quick transit, we have also been increasing our knowledge and enlarging our capacities,

by the facilities which mechanical inventions and chemical discoveries have afforded for the production of manufactures of every description. It will not be necessary to point out what has been done in cotton and the textile manufactures of the country generally; these have been as important as those of transport, and we have only to refer to the commencement of the present century to know that the skill and manufacturing energies of this country have been equal to anything that has yet been done in any other department of science applied to the industrial arts. The cotton manufacture of this country has quadrupled in extent within the last thirty years—those of flax, silk, and wool have increased in nearly a similar ratio; and but for the unfortunate war in America we should have accelerated the amount of production, accompanied with improvements in the manufacture, of great value to the country. Let us, however, hope that the present troubles may be suggestive of better times, and that we may again hear the busy hum of the spindle and the equally agreeable transfer of the shuttle through the shed of the loom.

When we contemplate the works that have been accomplished by science applied to mechanics, we must not forget what has been done by the chemist, as joint cooperator with the engineer, in the discovery and application of Gas to the various purposes of public and domestic use. Many of us remember the time of its first introduction, when the late William Murdoch first lighted his own house, (then Soho, at Birmingham), and ultimately Philips and Lee's mill at Salford, about the year 1804. Subsequently it was introduced to illuminate the streets, and now it is rendered subservient to light the carriages of railway-trains, much to the comfort and enjoyment of those who travel by night. To William Murdoch the country is indebted for the mechanical appliances and development

of Gas as an illuminating power; and when we look at the cleanliness, brilliancy, and security which it affords against fire, we are impressed with feelings of gratitude to the man who was the first to apply so cheerful and so brilliant a substitute for the pale and quivering light of the lamp and the farthing candle.

After Gas and Railways followed the Electric Telegraph, and here we are lost in amazement at the wonderful change the latter has produced. When we contemplate the elements of heat—if it be an element—and its repulsive action upon the molecules of matter, we are unable to account for the causes of its action, and the force produced by the enlargement and contraction of the atoms of bodies subjected to its influence. What relation electricity and magnetism have to heat has not been actually determined, or whether they are only modifications of the same element is uncertain, there being no experiments calculated to lead to conclusions of such vast importance to science.

Notwithstanding the imperfect state of our knowledge of electricity, we have attained sufficient experience to be aware of its existence and universal diffusion throughout nature; and we have been enabled not only to detect its presence, but have converted its action into a variety of useful purposes, and amongst others, that of being the vehicle of almost instantaneous communication between individuals at a distance from each other, and between the inhabitants of one country and another. We have moreover, by experiment and research into the properties of matter, found in the conducting powers of metals a ready and unbroken line of transmission—or, in other words, a single wire of copper or iron is sufficient to transmit a stream or current of this subtle fluid, with one-and-a-half times the velocity of light, to a distance of several thousand miles. This achievement of science would in itself be comparatively of little value,

if it were not for the disturbances or pulsations produced upon an instrument to which the conducting wires are attached at the termini at either end; and it is at the extremities of the wire that the ingenuity of man, guided by the unerring laws of nature, converts these pulsations into words, and reads off daily, on a large scale, not only private messages but long speeches, such as are now transmitted daily from the metropolis to the remotest parts of the kingdom. These instruments, insulators, and wires of the electric telegraph are amongst the greatest achievements of the age; and we have to thank our own countryman, Professor Wheatstone, and others for the discoveries and services rendered to this important branch of science, which contributes so largely to the welfare and security of mankind.

To the rapid communication of thought on land may be added other contrivances, by which a similar line of transit is submerged at the bottom of the ocean at depths varying from 2,000 to 3,000 fathoms. Here the slender wires, covered with an insulating material to prevent their contact with water or earth (which being conductors would carry off the currents) are entombed, but not defunct, as they retain sufficient vitality to guide and transmit the same electric force to the extent of some thousands of miles backwards and forwards from one extremity of the wire to the other. It is thus that we have established communications with almost every clime and every civilised nation in the world, and the time is probably not far distant when we may exchange words of import between this country and the New World on the other side of the Atlantic. These are some of the results of the present age, to which we are indebted for the numerous physical and intellectual benefits we now enjoy; and if we add to those already enumerated the advantages of the Penny Post, we arrive at a period in the history of science that has revolutionised the habits and customs of the world.

Having thus stated, however imperfectly, the changes that have been effected by the application of science to the useful arts, let us in our last division trace—

(3) THE INFLUENCE OF THE PROGRESS OF SCIENCE AND ART ON SOCIETY.

The close of the last century found this and other countries in Europe at war, but advancing in civilisation. The laws, although sanguinary in character, afforded protection; but science and art had made little or no progress during the antecedent period, and the people of this kingdom were deficient in intelligence and in those arts which have since contributed so much to the benefit of the community. At that time the steam-engine was scarcely known, manufactures were limited and comparatively unproductive, gas and steam-navigation had not been thought of, and railways, electric telegraphs, and the penny-post had no existence. In fact, all these discoveries and inventions are of recent date, and it is this generation and others yet to come that are destined to reap the benefits likely to flow from an age wherein the triumphs of science have been unequalled and unparalleled in the history of nations.

The influence which these discoveries have had upon the present and, as may reasonably be inferred, will have upon future generations is enormously great. We can now manufacture by steam-power to any extent: the mineral resources of this country within reach are almost inexhaustible, and the improved condition of the people fits them for an onward progress in all those industrial arts which contribute so largely to the wealth and prosperity of the country. When we consider these things, and look back to what we were and what we now are, we have reason to be thankful that we were born in an age of progress, and that we have been witnesses to the in-

troduction of the first principles of science applied to the purposes of everyday existence.

We have enumerated a few of the conditions which the advancement of our knowledge of science and art has bequeathed to the community, and even these are far short of embracing the whole of the influences which the improved state of our knowledge has exercised over the intelligence, comforts, and enjoyments of the great mass of the people. These improvements alone have developed increased intelligence, and caused a higher standard of character to pervade the homes of the lower and middle classes. The sphere of education has been greatly enlarged, and the moral condition of the people has been and still continues to be on the advance. This application of science to the natural and industrial resources of the country has, moreover, been of great value in stimulating the energies of all classes to still further applications, and the rate of progress has been wonderfully augmented in giving useful and profitable employment to the manufacturer and the artisan. On this question we have only to compare the amount of our commerce and the extent of our trade at the commencement of the century with its present increase, and the results will at once determine the influence which this acquisition of knowledge has had upon the enterprise and productive industry of the nation. The fact is, as I have before stated, that this new state of things has more than quadrupled the productive powers of the country, and these active agencies have diffused a spirit of intelligence amongst all classes of the community.

LECTURE III.

ON LABOUR: ITS INFLUENCE AND ACHIEVEMENTS.*

WHEN we consider the great objects of life, and what nature intended we should effect by labour, we arrive at the conclusion that we must work if we intend to live. This law applies to all conditions of men, from the savage to the highest state of refinement. The Great Author of Nature has evidently so constituted our minds and bodies that we should be dependent on labour for our subsistence,—hence the variety and abundance of material that has been placed at our disposal, and the wide field provided for the scene of our exertions. With the care of a parent over His children, the Creator of all things has not only stored the earth on which we live with the means necessary for our support, but He has bestowed upon it the stamp of Almighty power and the vital principle of life, in order that we may inherit all the advantages of an honest and productive industry. In the supply of such ample resources, the design evidently was that we should be dependent on our exertions, powers of application, and industry for the support and enjoyments of life; and hence the necessity of labour, which from the beginning of time has been the inheritance of all created beings. But we are not alone in the exercise of this principle, as the whole of animated nature, from the smallest insect to the largest quadruped,

* Delivered to the members of the Mechanics' Institute, Bolton.

has been doomed to follow the same undeviating course of labour in order to exist. We observe its constant exercise in the ant, the bee, and the beaver, and it is equally prominent in the larger animals; so that to live we must work, and there appears to be no living creature exempt from this general and universal law. Let us, therefore, endeavour in this inquiry to investigate in how far and to what extent a man is bound to fulfil the duties which nature has imposed upon him by a cheerful, ardent, and honourable pursuit of labour. I therefore venture to invite your attention, whilst I endeavour to show in what consists the peculiar properties of labour, as it applies to the different pursuits in which we are engaged, and its high and important duties, considered in our several capacities as individuals, and also as members of the great community of which we form a part.

In the discussion of this subject it will be necessary to divide it into two distinct heads—viz., *mental* and *physical* labour; and, moreover, it may be expedient still further to subdivide it into *skilled* and *unskilled* labour. In this arrangement I shall endeavour to impress on your minds—1st, That labour, of whatever kind it may be, is essential to our existence; 2ndly, That its influences are felt and appreciated by our immediate connections and by society; 3rdly, That it contributes to the comforts and enjoyments of life; and lastly, That its exercise is conducive to health, and is of inestimable value as regards our individual happiness. These are the chief points to which I have to direct your attention, and I hope I may be able to reconcile you not only to its duties, but to render it a pleasing and agreeable obligation which we owe to ourselves, to our families, and to society.

First, then, let us consider what is termed *mental labour*, or that faculty which comprises the exercise of the mind,

or those functions by which we become conscious and receive impressions through the senses. Now, this description of labour is one of the most important to which the human mind can be applied, as it involves the well being of society, and the happiness, utility, and comfort of individuals during the whole career of life. Everything, in fact, depends upon the state of the mind, how it is formed, what impressions it receives in early training, and how it may subsequently be applied for the moral and physical benefit of its possessor. There cannot exist a doubt as to the influence such early impressions have upon the individual for good or for evil, and the part he may be called upon to act in human affairs is to a great extent governed by them. Considerations of this kind are not always taken into account in the education of children, and the result is what is graphically described by an able writer on education: namely, 'that a child's brain at a very early age becomes a receptacle of facts and ideas to which at the time it attaches no importance—in reality, is scarcely aware that it has received them into the storehouse of its intellect; but being there stored, I believe such facts and ideas are not lost: they may remain apparently dormant for a time, but they have still that amount of vitality which awaits only its season for a good and sometimes a very inconvenient development. I hold that an idea thus received, although at the time the age of the child would forbid anything like a reasonable acceptance of its meaning, has notwithstanding a future influence upon it—at least thus far, that at a more advanced age it can develope it for good or evil, as it may be, and does often do so.' This opinion may be held to assume that the brain is, after a fashion, a material on which facts and ideas, coming through the senses, engrave themselves upon it, and so remain as written

matter, awaiting a time when the advanced condition of the child's understanding gives it power to read and apply them.*

* There cannot exist a doubt as to the functions of the brain, and the constructive character of the senses by which it is supplied with ideas. The first presents itself as the great recipient of our conceptions; and the latter the inlets by which they are received, mapped, and recorded, in order to be preserved and stored in that great mental reservoir for the benefit of the individual, and of those whom he may influence during the ordinary intercourse of life. The powers of discrimination, selection, and comparison seem to rest entirely with the brain. The senses are apparently subordinates, and may be considered as merely the tributary organs of supply in furnishing material to that great laboratory of the human mind, which, by a process of analysis unknown to anatomists, selects and separates the ideas which enter into the ordinary and extraordinary transactions of life.

Attempts have been made to classify and divide the brain into distinct departments, for the purpose of showing in what the tastes and propensities of individuals consist, but I believe we have no facts on which we can rely for such a division; and notwithstanding that phrenologists have written and lectured for the last half-century, we are still as ignorant as ever as to the intellectual process by which that important organ conducts the powers of reasoning, and fits us, through the powers of speech, to communicate and cultivate conceptions useful to ourselves, and we trust beneficial to others. It is true that phrenologists assert that we have evidences of the working of the brain from the enlargement and form of the cranium, and that the ideas which are most active are supposed to enlarge or protrude those parts of the skull in their immediate vicinity of action. This would be a most curious and most interesting question if true, but we have no proof that such is the case; as there appears to be nothing like facts to show that certain ideas are located in certain parts of the brain, and anatomists are agreed that there are no such divisions. As to the brain itself, it consists, according to anatomists, of two principal parts, which are duplex—the *cerebrum* and *cerebellum*, or great and little brain—and of the *medulla oblongata*, which is single. As far as we know, every part of the brain is employed in the performance of each function, and therefore to attribute separate functions to separate organs is neither more nor less than an unattested assertion. It cannot be denied that we have variously formed heads; but these formations cannot—as far as I know—be traced to the internal working of any portion or any part of the brain. On the contrary, the brain follows the law of growth in common with every other part of the body; and we shall best perform our duty by studying its functions, and endeavouring to furnish it with a store of useful ideas, to enlarge its capacity, and fit it for the ordinary duties of life.

In confirmation of these views, I firmly believe that the future of the man may be traced to impressions on the brain received in childhood; and it behoves parents to be careful to whom they entrust the education of their children, in order that the youthful mind may be stored with ideas adapted to its perceptions and to its future career in life. To mothers of the working-class, in particular, it appears most desirable that they should study for themselves, so to govern their tempers, actions, and conversation, as to produce such impressions on the minds of their children as may lead to a true and correct sense of the obligations they owe to truth and that integrity of character which marks the conduct of the intelligent and hardworking poor. These considerations are all-important to the working-man in the selection of a wife. He should never lose sight of the idea that she is the instructress and schoolmistress of his family—that her example, conversation, and bearing is what her children will imitate; and, be it for good or for evil, children will inherit to a greater or less degree the impressions they receive in that stage of early culture, which more immediately belongs to the mother than the father of a family. A father is nevertheless, according to my opinion, by no means exempt from his share of domestic duties, nor of what is due to a good and virtuous wife in the training of his children. In this fortunate position he is bound in duty, independent of his outdoor labour, to give his affectionate and willing support—to encourage, by tenderness and care, the good work she has in hand; and at a more advanced stage to confirm, by his assistance and example, the truthful moral principles first established in the mind of the child by the mother.

The acquisition of knowledge, or ideas impressed upon the mind, is not acquired without labour; and its subsequent application, arising from thought, when directed to

science or the social purposes of life, is what may be called mental labour, in contradistinction to what is generally known as physical exertion. Every description of labour is, however, commendable when it has for its object the increase and maintenance of our intellectual and industrial resources, and the man who applies it for the purposes of instruction deserves well of his country and the society in which he moves. Mental exertion is that kind of labour by which we arrive at certain definite ideas, which retained in the mind, or carried into effect for a particular purpose, will produce certain results; or, in other words, they form such a combination of ideas as are calculated to enlarge our conceptions by the creation of other ideas, which not unfrequently occur to the studious in the pursuit of knowledge. Ideas or emanations of the brain, arising from study and thought, may also be considered as mental labour, and belong chiefly to men of literary and scientific attainments, or to the learned professions, where the exercise of intuitive perception and a sound judgment are the only true harbingers of truth. We must, however, remember that these functions are present in a greater or less degree in every description of labour, whether it be mental or physical; as no man has the power of muscular exertion without the exercise of the mind, which gives the will to the act, and regulates the movement of the muscles by which that act is performed. It is obviously correct that we may be unconscious at the time of an act of volition—as in locomotion when walking with a friend, or engaged in thought, we are not conscious of the motion of the body or each successive movement of the limbs; yet there can be no doubt that the acts are our own as much as when we are attending to or conscious of the exertion, and in either case it depends on ourselves whether we continue or discontinue the motion. If, for example, a man has to cut a trench or dig a piece of ground, the very movements

of his hands and feet, and the position, depth, and size of the cut, are determined by the conception which governs the force, form, and condition under which those movements are produced. It is true that they require no great labour of the mind to produce them, and may safely be considered as classed under the designation of involuntary actions, which are not peculiar to man alone, but are present in all animals. There is, therefore, this distinction between mental and physical labour—namely, that of intuitive motion of the muscles, which does not embarrass the intellect, in the former; and in the latter those of thought and reflection, which fatigue and sometimes—when carried to excess—injure the functions of the brain. I have been drawn into these reflections not so much from the desire to show the difference between mental and physical labour, as to point out the intellectual as well as the physical advantages of labour pursued as a duty; and forcibly to impress upon your minds not only that labour is one of the necessities of life, but moreover that it is the only true and cheerful companion of our existence.

Having shown that labour is a natural law from which none of us are exempt, let us now consider how we can make it agreeable and useful. To effect this we must not procrastinate in its performance: procrastination is the thief of time, and the general excuse of the indolent and the lazy is—'*There is plenty of time*; it will do to-morrow.' To-morrow comes, and it will do the next day; and so on it goes till the labour is lost, and the work is never done. Now, this is a most unsatisfactory condition of the mind; as it not only deprives us of the reflection of having faithfully and promptly done our duty, but it reproaches us with having, from indolence or some other frivolous cause, neglected it. But the mischief does not always rest here, as the non-performance of duty at the proper time leads to dis-

order and confusion in our affairs, and produces the same mischief in the affairs of others. Besides, we may lose from this cause the opportunity of benefiting a friend or performing a public duty; and again, it is unfair to burden to-morrow with work that does not belong to it: to charge it with labour not its own is evidently not a fair allotment. I would therefore caution you never to forget the value of time. Time is money, and I would advise you to make the best use of it: and whatever you have to do, do it, according to Scriptural teaching, 'with all thy might and with all thy heart,' and it will be well done. As labour appears to be the lot of all created beings, and as it is essential to health and happiness, we ought to hail it as of inestimable value, and moreover we should lose no opportunity of making it useful in our different positions of social intercourse. We complain of lassitude and fatigue after long-continued exertion, but this feeling applies to the brain as well as to the organisms of the body; and nature, ever true to her task, provides a remedy for the spontaneous and willing discharge of both mental and physical exertion. A few hours' repose not only restores the exhausted system, but comes upon us with a pleasurable sensation and a degree of soothing softness, which we cannot too highly appreciate as a boon from nature and a relief to all our toils. That restoring principle of refreshing rest is an ample compensation for all our labours, and these alternate changes from labour to rest, and from rest to labour, are of themselves the reward and solace of life. But this is not all, as an honest discharge of the duty of labour engenders feelings of satisfaction and repose. It claims for itself reflections of the most pleasing description, and enables us to look back upon the performance of good actions—freely and disinterestedly performed—with a degree of gratification which cannot be too highly prized. These reflections are always present to the mind of the

honest labourer; and the consideration of its due performance for a long series of years, in the varied duties of a son, a husband, or a father, is probably one of the greatest blessings that can be conferred on the infirmities of age.

These appear to me to be some of the intellectual results of labour; but, according to my view, it furnishes, in addition to the results enumerated, rewards of a more substantial character, and its discharge is never-failing in its tendency to ensure a large and ample return. To illustrate this by example, let us suppose that a farmer, as cultivator of the soil, prepares his field for the reception of the seed. Nature—true to her laws—rewards his labour by the increased fecundity of the soil, which in due time reproduces and multiplies the return, in some cases fifty and in others an hundredfold. Again, if we take the mechanic or the artisan, and examine how he is rewarded for his labour, we find that his wages are the representatives of as much food, clothing, and other necessaries as his earnings will purchase; and on many occasions, if he exercises the head as well as the hand, his increase of knowledge enlarges his powers of production, and he becomes a skilled labourer of much greater value to his employers than he otherwise would have been in the capacity of a common workman. In this position his wants are better supplied, and he obtains the means of procuring not only the necessaries but sometimes even the luxuries of life.

Now these are the points to which I wish to direct your attention, to stimulate your exertions, and inform your minds. I do not wish to see the working-man a mere machine, but an intelligent and a thinking being; and I am sure he will best consult his own happiness if he studies to cultivate his mind, as a safe guide to the skilful operations of an intelligent workman. There is no labour so

low as not to require the aid of the head as well as the hand; and to do this effectually requires thought and consideration, in order that the work done may be of the best quality, and accomplished with the least possible expenditure of physical force. In this we arrive at a combined process of mental and physical exertion, and to this point I am desirous of raising the faculties of every working-man, for the double purpose of making him more useful to society, as well as to those with whom he associates and for whom he labours. There are, however, some descriptions of labour which do not require much mental exertion; and these may be classed in what is called the act of rotation, or a repetition of the same thing over and over again. To this class we may safely appropriate manufactures produced by automaton machinery—such as the steam-engine, the water-wheel, and every other description of self-acting tool or machine which does the work without the assistance of the human hand, and which requires simply the process of feeding and attention to continue its progress in the fulfilment of the duties it was intended to perform. This kind of labour is to some extent monotonous, but the attendant's mind is greatly relieved by the combination of motions and the exactitude with which the work is performed; and no man of thought or reflection can witness the complicated movements of the steam-engine, the spinning-mule, and many other machines of the self-acting kind, but must ponder and think how these things are accomplished, and how beautifully they effect the objects for which they were constructed.

In this sketch I have endeavoured to show the uses and value of labour; let us now consider wherein consist its influences, and to what extent it is beneficial to the community. Labour in this respect is productive of much good, as its influences extend to all classes in promoting a spirit of emulation and enterprise, and a desire to rise in

the estimation of our fellow-men. It stimulates our exertions to obtain knowledge, to increase our wealth, and to attain distinction in our respective professional callings. These are the offspring of labour, and there is no denying that their influences are such that most of us will make any sacrifice to attain consideration in the eyes of the world. The senator, the soldier, and the sailor will labour at the risk of their lives to attain that object. And when this is done from an ardent love of his country, its government, laws, and institutions, it becomes an honourable ambition which deserves public acknowledgment, and to which everyone is entitled who is willing to make such a sacrifice in the path of duty. That labour influences all classes of men does not admit of doubt. We may select, for example, a young man of character, commencing his professional career with a desire to better his condition, and to attain for himself a name for probity of character and untiring perseverance; in fact, we may suppose him to be ambitious, full of energy, and a determination to conquer every difficulty, and to attain the object for which he labours. Now in cases of this kind every right-minded person will applaud and promote his exertions, and will render him assistance in the laudable and good work he has before him. Such a man is an exception to the general rule, but there are such persons, and they seldom if ever fail to make an impression, and produce influences which leave their *marks* upon society for succeeding generations to imitate. Let me hope that in this assemblage there are persons of that class, — young men of energetic minds, endowed with a spirit of perseverance, and fired with an ardent desire to distinguish yourselves as benefactors to mankind.

Independently of what may be done by individual exertions in the pursuit of an honourable and useful industry, there are other considerations and influences to which I

would refer, as affecting a wider circle than the narrow range of our own immediate friends; for the career of a laborious and industrious life, when presented to the world, is not without its influences on society. This becomes the more evident, as such a life presents for imitation a rule of action which never fails to make an impression upon the minds of a rising generation. The spread of knowledge and the influence of example have therefore much to do in the formation of character. They become almost identical with the interests of labour, and the man who works hard in the pursuit of an honourable and an approving duty will best consult his own happiness and the interests of society.

Before I conclude, permit me to lay before you what I consider to be the result of all this hard work, this constant toil, that I have been endeavouring to urge upon your attention. In the title of this paper I have called it 'The Achievements of Labour,' and I think it an appropriate term, as it indicates work, or something to be done. It also implies reward, or some other advantage, as a compensation for the time and exertion bestowed upon it. That this is actually the case we have abundant proofs, as there is no labour without results; and these are so numerous, interesting, and conclusive, that I have only to mention a few of them to convince you that in every branch of industry, in every honourable pursuit, *labour is not without its reward.* Let us refer to a few of the more prominent cases: and without going back to the labours of the heathen philosophers, we have in modern times many triumphant examples of the achievements of labour in science and art, from the days of Galileo's discoveries to those of more recent date. The labours of that distinguished love of science have led to discoveries of the most important description. Happening to be one day in the metropolitan church of Pisa, he remarked the

regular and periodical movement of a lamp suspended from the roof of the cathedral. He also observed the equal duration of its oscillations, whether great or small; and afterwards, by repeated experiments, he perceived the use to which it might be applied for the exact measurement of time. The idea was, fifty years afterwards, applied in the pendulum to the construction of clocks, now in universal use. The hydrostatic balance also, for weighing bodies successively in air and water, owes its origin to Galileo. The thermometer, as a correct measure of temperature, sprang from the same fertile brain, and the sector, intended for the use of military engineers, flowed from the same source. All these important discoveries were the rewards of labour and deep research; but his crowning effort was the invention of the telescope, which, applied to celestial phenomena, enables us to penetrate into space, has extended our knowledge of the heavenly bodies, and elevated our conceptions of the infinite wisdom and power of the Great Ruler of the universe.

It would occupy too much of your time to enlarge upon the labours and discoveries of Galileo. You may rest assured they were incessant; and when I tell you that he died at the advanced age of seventy-eight — the very year on which his successor (Sir Isaac Newton) was born— you will perceive that his numerous discoveries were soon to be rendered practically useful. Newton, like Galileo, was the first to establish the refrangibility of the rays of light, and his idea of gravity as the cause of celestial motion was discovered in the year 1666. When sitting in his garden at Woolsthorpe, the doctrine of universal gravitation took possession of his mind—as it is said—from the falling of an apple. This idea never left him until he had proved 'that every particle of matter is attracted by gravitation to every other particle of matter, with a force inversely proportional to the square of the distance.' This great dis-

covery and its application to the movements of the planetary system are not only well known to astronomers and men of science, but are familiar to most persons, and therefore require no further illustration in this place. Newton, during a long and useful life, laboured hard in the field of science, and his discoveries in optics and chemistry are so important as fully to justify what is now invariably understood and generally considered as the foundation of the Newtonian philosophy.

In addition to the great names I have mentioned, allow me to state that the labours and discoveries of the present day are not behind, if they are not considerably in advance of, any previous age in the history of science and the useful arts. We have recorded some of the works and discoveries of a former period; but if we compare them with the changes, discoveries, and inventions that have taken place from the introduction of the steam-engine to the present time, we arrive at the conclusion that the minds of men have not deteriorated, but are greatly enlarged in those departments of science which have led to such wonderful results. Let us examine into the labours of some few of our immediate predecessors and some of our contemporaries, and we shall find that more has been done —with all due respect for the great names I have mentioned —during the last eighty years for the benefit of mankind, than ever was accomplished at any previous period in the history of the world. Look at the labours of James Watt, and observe with what assiduity and perseverance he pursued the object of his ambition—with what skill and patient research he studied to ascertain the force, density, and other properties of evaporated water—and the high order of mind which he brought to bear on latent heat, and the laws by which the procuration and use of steam were governed! These important researches led to results of which we now reap the benefit, but it is not to them alone that

we have to refer; there exists a still higher order of intellect, which he brought to bear on the mechanism of his engine. His invention of the separate condenser, the sun-and-planet and parallel motions, and the governor, by which the whole of these beautiful movements are regulated, are sufficient to immortalise James Watt as one of the first benefactors of the human race. The steam-engine, and its application as a motive power to every description of manufacture, has increased the resources of this and other countries beyond our most sanguine expectations, and its results are without a parallel in the history of nations. It has been applied to navigation with a force and efficiency that sets wind and tide at defiance; and it has opened up and brought into direct communication the inhabitants of other countries, that are separated from us by wide and pathless oceans. To the labours and fertile brain of Watt may safely be attributed these results, and to the same intellect and those of his able successors we may trace its introduction to locomotion and the railway system, so energetically and perseveringly forced upon the public by an old friend of my own, the late George Stephenson.

George Stephenson, although the Father of Railways, could scarcely be called an inventor or a man of great intellectual capacity. He was, however, equally useful and equally successful in all his pursuits; and we have only to witness the result of his labours on the Killingworth, Darlington, and Liverpool and Manchester Railways, to accord to him the merit of a hard worker, a distinguished engineer, and a man of indomitable perseverance, to whom we are indebted for the first successful railway worked by locomotives. Since that time many improvements and many discoveries have been introduced.

We are all of us intimately acquainted with what exactitude the great luminary of our planetary system is—

by his radiant powers of arrested light—converted into an artist true to nature in the minutest details; giving to us that beauty of form which, in landscapes and many other objects, are by this process so elaborately and faithfully portrayed. In other words, the light of the sun is, by a simple chemical process, made to imprint with minute exactitude, on a properly-prepared surface, every object that is brought within its influence in the focus of a camera-obscura.

In this discourse I have endeavoured to establish—*first, that labour is inherent in man and in animals; secondly, that its use is important and ought to be cultivated; thirdly, that its influence is powerful and effective; and lastly, that its achievements are great.* These are the results of labour, and I recommend them to you as your best hopes and your only true and faithful companions through life.

LECTURE IV.

ON LITERARY AND SCIENTIFIC INSTITUTIONS.*

HAVING been called on by your Directors to offer for your consideration a few remarks on the institution we are met this day to inaugurate, I have, in compliance with that request, in the first place to congratulate you on the highly gratifying sight of so large and so influential an assembly. To myself this highly respectable meeting is the more encouraging, as it shows a determination on your part to carry out to the fullest extent the objects contemplated by the originators of this institution. As a stranger to the local interests and necessities of the town, I am not the person to judge of the expediency of such an undertaking. But this I know, that the establishment of an Athenæum in the centre of this important and rising community must prove highly advantageous, and doubtless will produce the most salutary effects upon the inhabitants of the district. It will, moreover, be a point of attraction to visitors who, in search of health or pleasure, may fix their residence in your town. The mildness of the climate, the salubrity of the air, and, above all, the good feeling and hospitality of the inhabitants, aided, as I hope they will be, by the intellectual resources of your Athenæum, are inducements that are certain to be appreciated; and I look forward with certainty and satis-

* An Address delivered at the inauguration of the Southport Athenæum.

faction to the results of this meeting, as commencing a new era in the history of Southport.

I well remember in early life, when my family were young, and when we made an annual visit to Southport, that there was no Esplanade, no Pier, and no Athenæum; in fact, I much question whether there was a public library in the whole town. The sandhills were, however, more numerous, and so close at hand that the fresh fish of those days was always in season if the wind happened to blow from the west or south-west. Antecedent to that time (I believe about the year 1796), an old friend of mine used to tell that he visited Southport when there were not a dozen houses on the spot which now contains 12,000 inhabitants; and that there was such a want of accommodation that he had to sleep in the hayloft of the only existing inn, at the south end of the village. In my own time the only house of entertainment was that of old Harry Rimmer; and as Harry played the fiddle, his visitors never failed to have a dance on the green. These primitive days are, however, gone; and those of modern Southport have brought with them all the luxuries and endowments of a rising and flourishing community. I must not, however, dwell on the past; it will be more cheering and more acceptable to look to the future. I am, indeed, no magician to divine, or prophet to foresee, what the future may bring forth; but I think I may venture to predict for Southport an increase of wealth and a continuance of prosperity. I might use the phrase 'a finished town'—but that time may be distant: what we have to deal with at present, is to attain the elements of success, and the establishment and endowment of institutions like the present, calculated to attract the stranger, and furnish the means of intellectual improvement. All these things the past and present history of Southport seem to promise; and I have once more to congratulate you on the occasion of

this meeting, fostered, as I hope it has been, by the higher aspirations of intellectual culture.

On a careful perusal of the rules and regulations of the institution, it is distinctly observable that it has not only an object calculated to instruct and amuse, but that it is educational, and offers to the young, as well as to those who have reached maturity, a large fund of information in its library, reading-room, and lectures. These are the attractions of your new institution which I hope will be fully appreciated, and if properly and judiciously employed they will lead to the very best results. I do not for a moment suppose that the members who attend the library and reading-room are to commence a new system of tuition; but I have reason to believe that a good library of well-selected books, a reading-room, and occasional lectures on literature and science, must prove highly beneficial to the subscribers, and especially to the younger branches of the community, who may attend the classes and reap the benefit of a strictly educational course.

Having thus stated the objects of your institution, let us now look to its working, and the benefit and instruction that may be derived from its establishment in the centre of an intelligent although somewhat variable population.

In this attempt I shall have to adopt a methodical arrangement, in order to show, as succinctly and as clearly as possible, the different stages through which we have to travel in order to attain the object of our search. First, then, there are in this institution four distinct roads by which we may obtain knowledge and improve the mind—namely, Reading, Conversation, Lectures, and Study. There is yet another, Observation; but that is not specially encouraged by this institution, although it is one of considerable importance as regards the acquisition of knowledge, and one of the best and most agreeable schools in which a learner can study—namely, that of a large and extended

field of observation. This does not, however, come under any distinct branch of education, but must be left to the taste of the student himself.

In my endeavour to inculcate the best and most direct methods of acquiring knowledge, I shall probably have to treat of my own personal experience, to show how I became possessed of the little I know, and the methods by which it was attained. You must bear in mind that I had to begin life with few or none of the advantages of most of my hearers, and in the absence of elementary instruction I had to supply the deficiency by extraordinary eagerness in educational pursuits before I could pass the rubicon. I may mention that in my younger days we had no Mechanics' Institutes, no Literary Institutes, no Athenæums. Nothing of the sort existed, especially in such a small town as my native place was: and those young men who were poor had no means of obtaining a regular education, being merely taught to read and write, and a few of the simplest rules of arithmetic; afterwards they had to become their own masters, and teach themselves in every other branch of knowledge. In these pursuits let me observe that *self* is a capital master; he is never absent from his pupil, and is closely identified with his success. It is wonderful how the scholar improves, and how well he fructifies under so good and so excellent a teacher. Take my word for it, therefore, that there are worse masters than *self*—and that instruction, when properly and judiciously applied, will in nine cases out of ten lead to honour and distinction. Several of the great men of this country have risen to eminence almost exclusively by their own exertions; and I believe there are no instructors so proper, so powerful, or so successful as we are ourselves, when acting as our own masters.

Having thus referred to what may be done by individuals with limited time and limited means, let us consider—

THE ART OF READING AND HOW TO READ.

Reading is an acquired power of the mind, whereby we become acquainted with what others have written, and with the sentiments and thoughts of the learned men of the world, almost from the beginning of time. In reading, we are associated with the author in his feelings, thoughts, and ideas; and we naturally lean to his reasonings and opinions, provided they bring with them convictions that satisfy the mind. To be assured that such convictions are founded on truth, we must think and judge for ourselves, and compare the facts and reasonings of the author with our own experience, and the statements of others qualified to form an opinion on what they read. On scientific subjects the reader can never be at a loss, as in these he has to deal with the exact sciences, which are demonstrable when founded on fixed and determined laws, to which every assumption must yield, and with which he must make himself acquainted. In this line of reading he will find himself amply rewarded for the time and trouble he has bestowed upon the author, and, moreover, he will have the satisfaction of knowing that he has treasured up in his mind a fund of knowledge, to which he can refer in the various pursuits of study and the ordinary occurrences of life. In works of Fiction we are often transported into the ideal world, and those fairy scenes which, although beautiful and ethereal, vanish at the touch of analysis, and which, delightful as highly-finished pictures, are better calculated for occasional amusement than for daily use. Poetry is another attractive study—which also deals largely with the ideal; and when true to nature, as in Burns, Byron, and Shakspeare, it cultivates the higher faculties, and expands the intellect and powers of imagination into a region of new creations teeming with wonder and delight. In the writings of

our best poets we meet with the highest flights of imagination, and we read them with a delight bordering on inspiration. I well remember my own early readings of Milton, Dryden, and Shakspeare, and others of more modern date, and still retain a lively recollection of the sublime and lofty conceptions of Milton's 'Paradise Lost.' For instance, the gifted author, when dilating on the Divine fiat to Michael and Gabriel, the commanders of the celestial hosts, sublimely announces the power invincible—

> Go Michael, of celestial armies Prince
> And thou, in military prowess next,
> Gabriel, lead forth to battle those my sons
> Invincible, lead forth my armed saints
> By thousands and by millions ranged for fight.

Historical reading also requires careful consideration, and I know of no subject so interesting and instructive as that of History: every well-educated person should make himself acquainted with the history of his native land, and with as much of the history of other countries as time and circumstances permit. This species of knowledge we can always turn to account in the voyage of life. My own early readings in History were Plutarch's 'Lives,' Gibbon's 'Decline and Fall of the Roman Empire,' 'Charles V. of Spain,' and 'Mary Queen of Scots,' Hume's 'History of England,' and more recently that of Macaulay. To these may be added Prescott's 'Conquest of Mexico and Peru,' and the writings of other distinguished historians, such as Hallam, Grote, &c.

Biography is another department of reading of a most attractive and most influential description. To read and to study the lives of eminent and distinguished men is always an agreeable task, and to trace from small beginnings the rise and progress of an honourable ambition, and the ultimate success of a never-tiring perseverance in pursuit of knowledge, is above all others the most instruc-

tive lesson for the young to cultivate. Let us therefore hope that a carefully-selected class of biographical authors will be found on the shelves of the library of this institution.

With respect to Natural History and Science, I would advise the young students of this institution to observe, that they require mature consideration and thought. The meaning of the author must be clearly understood, and by meditation and repeated readings the student should make himself master of the problems, demonstrations, and formulæ connected with the subject.

These studies should never be neglected in our national institutions, and it is marvellous that this country—which, above all others, is famed for the extent of its manufactures, mechanical skill, and extensive practice in the useful arts—should be wanting in schools and institutions for teaching youth the elementary rules of their respective professions: these of all others are the most important to the community, and the best calculated to enhance the value and extend the influence of our industrial resources. In my opinion every person should be taught the rudiments and higher branches of their professions, upon the same principles as barristers and physicians are taught. For example, all persons intended for professional pursuits in connection with the constructive arts should have a theoretical as well as practical education. They should be instructed in the fundamental rules connected with their trades and callings, or, at least, taught as much of theory as would enable them to enter upon the practice with some degree of certainty, and that more especially in the practical development of those principles on which the safety of the public and the success of their professional career depends.

It is absurd to talk against theory, as if a knowledge of the exact sciences was a dangerous and a useless attain-

ment: nothing can be more erroneous than this impression, as on close inspection there is no practice without theory, any more than there is no effect without a cause. In the useful arts theory can only be considered dangerous when it is not reducible to practice, and where it tends to error on false principles, which, in fact, is not theory but assumption. The true meaning of the term *theory*—which creates so much alarm in the minds of practical men—is neither more nor less than a series of definite rules by which practice is governed, and through which we derive, from fixed and definite laws, those sound and unerring results, which of all others is the primary object of practice to accomplish. Let us, therefore, abandon the 'rule-of-thumb' system, and cultivate true principles, which should never be separated from the twin sisters of Science and Art.

Of all branches of human knowledge the Natural Sciences are the most important. We speak of our inventions and discoveries, but how simple and effective they become when once they are known! We sometimes arrogate to ourselves the discovery of new principles, but, in truth, there are no principles which are new. All right principles existed before our discovery of them, and our science is nothing more nor less than an unveiling of the universal and eternal laws of nature. I know that there are many people who suppose that discoveries and inventions, either in physics, chemistry, mechanics, or any other subject, are really new discoveries. They may be new to us, but they pre-existed, and the discovery or invention—if such we may call it—is the addition of existing principles to our stock of knowledge, with which we were previously unacquainted. There is nothing new in nature; all that we can do by our meditations, thoughts, and experiments, is to discover what are the true laws that govern the universe, and the principles on which everything it con-

tains is founded. Having done this, and perhaps given to the world a so-called invention, such as causing electric currents to pass along the slender wire, or the art of photography, things not known before, we do not in reality invent anything—we are simply discoverers. Let us therefore, in our reading, whether it be in science or in literature, be humble under the conviction that everything that is good, worthy, and true, first existed in the mind of the Great Author of all that surrounds us. Whilst speaking of reading, allusion may also be made to the art of writing; and here I am reminded of a phrase of Sir Richard Arkwright, when he experienced some difficulty in reading a letter. A friend who was looking on said that it was well written: Sir Richard—looking him in the face—answered, 'Ony foo mut write, mon, but it is the devil an' a' to spell.' The fact was, that Sir Richard was never a good writer, and a still worse speller; hence the difficulty of reading what in other respects might safely be called a legitimate letter.

Writing is, however, an art of great importance, and I would advise my young friends to practise it with the utmost care. It is so closely allied to reading that I am almost tempted to recount, for the information of others, my own practice in early life. I make no doubt there are many here who, like myself, had to labour under difficulties for want of rudimentary instruction, both as regards grammar and composition. I attained the art I have acquired—such as it is—not, I can assure you, by taking for granted that I could write, but that I wrote imperfectly, and without knowledge of style or composition. To attain a clear and explicit expression I had to read and to study; and the great art I had to acquire was to be sure not only that I understood what I had written, but that the meaning would be conveyed to others in a clearly intelligible form, so that every idea should leave

on the mind of the reader an unobscured and distinct impression. In a word, I wished to put the whole of my own conceptions into the possession of those who might take the trouble to read them.

In these exercises you will observe I had no master, nor had I the privilege of an acquaintance with Greek or Latin. But I had a craving appetite for distinction, and in order to remedy educational defects, I read the best authors, such as Addison and Steele, Hume, Smollett, and Goldsmith; and I was ambitious enough to place myself in competition with them, and established a system of mental rivalry, which I carried on for some years, with improvement, but comparatively to my own discomfiture. After reading an essay or passage I would close the book, and, with the train of reasoning fresh in my mind, attempt to write the article in my own way, and my own style. This I found good practice, as it humbled me in my own estimation, and thoroughly convinced me of my own want of skill, when contrasted with the language of the eminent men quoted above, and to whom I am indebted for the limited knowledge I possess.

I do not offer these facts in a spirit of egotism, but to show that original defects in education need not prove an impassable barrier to improvement, where there is a strong determination to enlarge the mind and cultivate the intellect. I therefore give this as an example which others in the same circumstances may follow, with at least some chance of success, if they choose to adopt the same methods which were serviceable to myself. I am not sure whether I am right or not; but I have a strong impression, and believe it is shared by most minds more or less, that if we have any object to accomplish, whether it be to gain a certain amount of knowledge in any science, or to make any desired discovery, we must make up our minds never to lose sight

of the end we have in view, steadfastly to persevere, and, unless our object be utterly unattainable, or not existent in nature, we are sure to succeed if we bring all the powers of our minds to bear upon it.

Conversation, next to reading and writing, is perhaps the most agreeable mode of imparting and receiving knowledge, and this faculty is largely exercised in every community. It is what I would call the exercise of social science, and, when properly conducted, is most important and beneficial. It is indifferent on what subject our conversational powers are exercised; they are always persuasive, always agreeable, and—when the subject is judiciously chosen and properly handled—always instructive. It is the same whether it be in the Athenæum or in the domestic circle—it is necessary that our conversation be instructive, as it becomes essential to the advancement of good feeling, in quarters where it is truly valuable.

This practice, when judiciously applied by the heads of families, is of vital importance in the training of young minds, which in almost every case are moulded by the impressions received on the domestic hearth. If this be correct, how very important it is that the conversational powers of those who have the tuition and management of children should be well cultivated, and their minds governed by sound principles of morality and truth! In the early stages of our existence the mind receives impressions which have great influence on the actions of after-life; and much depends upon the mother and those who have the training of children, that these impressions are of the right kind, and that they have the stamp of truthfulness and virtue. In all future developments, therefore, how very much depends on a mother's actions, manners, and conversation! The future happiness and wellbeing of her family are almost exclusively in her hands, and how very essential is it therefore that we should have good mothers!

These considerations would lead me to the great and important question of female education; and hence it follows, that the first step in our educational career should be applied to the gentler sex, in order that our minds may derive from that source the germs of correct mental culture, and those high principles of integrity and virtue which mark the honourable and useful members of the community.

It is supposed that the female mind is not equal to the sterner duties of our own sex. This is, however, not altogether true, as we find that the minds of women, with their finer feelings and their quickness of apprehension, are in many cases superior to those of men; and, moreover, that they are not only susceptible of large development, but for penetration, quickness of perception, and high attainments in mental culture, they are fully equal to the more rigid characteristics of the other sex. Let us therefore, in this institution, look forward to a department in which the future mothers of Southport may receive the rudiments of a virtuous education, calculated to transmit to their children and to society the enduring benefits of an honest ambition and a well-spent life.

In addition to ordinary conversation, I would recommend the formation of a debating society, as soon after the institution is at work as possible, in order that questions of literary and scientific interest may be discussed. The only consideration to be observed in this case is the avoidance of religious and political controversy in regulating the debates, so that a spirit of inquiry may be fostered, and friendly associations cultivated and sustained. A society of this sort, with another for athletic exercises, will prove of incalculable value to the youth of Southport. With regard to a debating society, I do not mean such as are found in many places, where all sorts of subjects are introduced, often leading to mischief. What I recommend

is a discussion society, where the subject is carefully selected and considered, and ably discussed; and I would advise the members of such a society to come forward with notes taken from their readings and their own thoughts on the subject before them, so that they may discuss the matter in a dispassionate, friendly, and controversial spirit. If this were done, I think that the society would prove highly useful, and, besides, give to some that elegance and fluency of expression which, to my great regret, I do not possess.

Lectures are another form of instruction of great value; and the younger branches will do well to take notes, so as to apply the knowledge they may receive in this way to the purposes of after-life. Lectures on science require more than ordinary attention, if we intend to benefit by the elucidation of facts and experimental research. These cannot be disposed of *en passant*, but must be considered, weighed, and matured, in order to render them useful to the learner, and to enlarge the mind on the fundamental principles of natural and experimental science. In confirmation of this mode of instruction, I may notice that the practice of imparting knowledge by lectures is general in our colleges and universities; and that it has its advantages may be seen from the numerous students that attend with their notebooks, to which they can refer when their minds are more matured by reflection and study. I would therefore encourage this system of instruction as highly advantageous to the members of the Athenæum.

Meditation, or *study*, is the concluding subject to which I would solicit your attention, and I think you will find it includes those exercises of the mind, whereby instruction, gathered by all the previous methods to which I have alluded, is rendered useful. It fixes on the memory what we read; it corrects errors, and matures the judgment. It is by meditation that we detect what is wrong and adhere to what is right, and by the exercise of a sound

judgment it balances the elements of choice, and attains correct conclusions. The power of intellectual analysis is a wonderful achievement of the human mind; and when we consider its workings by comparisons, and its power of selection, we are lost in wonder at the gift bestowed on us by the Great Author of our being. How thankful, therefore, ought we to be for powers of such excellence, and how careful should they be exercised, in order that we may secure the greatest amount of good for ourselves and all those with whom we are connected! Reflection has another curious and interesting characteristic, which exists in every mind, but which I much fear too frequently escapes our notice—and that is a power of calling forth an imagery seen only by the mind's eye. To this faculty we do not attach sufficient importance, and I would here note that this 'building of castles in the air,' as some persons call it, is one of the pleasantest and most agreeable occupations of human existence. Let me ask anyone here present whether he has not experienced sensations of delight in having pictured to himself objects which it has been his earnest wish to attain, and whether these objects have, or have not, stood before him in all their due proportions of figure, magnitude, and beauty? They are generally modified according to the wishes of the thinker, and they are also often exaggerated, unless corrected and brought within limits by the governing power of reason and experience.

On this subject I will only mention what has frequently passed through my own mind with regard to what is very difficult to understand—with all our philosophy, and all the powers with which nature has gifted us: I mean the act of volition. For instance, you find that in playing on a violin, piano, or any other instrument, the fingers pass over the different keys without any apparent thought or effort of the mind; yet the impression of every one of

these notes, however rapidly produced, must first pass through the brain before the movements are effected and the fingers perform the functions of volition. It is evident that we are endowed with powers to produce this harmony; but during the performance, we do not think for a moment whether we are touching the instrument right or wrong. Our fingers seem, by a sort of intuition, to fall on the proper notes without the aid of the mind at all, but that function is nevertheless the exponent or index by which the movements are produced. Attempts have been made to solve the working of these functions; but, with all our knowledge, we are unable to obtain clear and definite conceptions of the union which exists, and we are totally at a loss to unravel what appears to be a mystery from beginning to end.

In my own professional career, I have always derived satisfaction from the silent contemplation of the *pros* and *cons* of new and untried ideas. If I wanted to achieve a novel and difficult construction, the first step in the way of discovery was to form an image of the whole in the mind; to select the material, sink the foundation, and raise the superstructure; to weigh and balance the parts, until the whole system of organisation appears before the mind, a finished and complete structure, as if in actual existence. It must be evident to most persons, in constructing a house for instance, that we first think of the building in its outline, its various forms and proportions, before the design is complete. If we want to make improvements in the kitchens, rooms, lobbies, and other parts, we map them all out beforehand in the mind, and, in fact, we build an ideal house before we attempt to erect a material structure of a more tangible form. If this is done by meditation and thought, corrected by reason, judgment, and experience, we seldom go wrong in our estimate of what is to be done and how to do it. There is another

quality of the mind arising from thought, and that is, the facility by which we can drop one subject and take up another. Some people have quicker perceptions and greater aptitude in making this transfer than others, but all of us possess that power, and it only requires exercise to render it active. Barristers, for instance, have great facilities in that way; and I must confess all may attain it, in a greater or less degree, by arrangement and organisation in collecting our ideas, and bringing them to bear with their whole concentrated force on the subject to which they are directed. Now, this admirable property of the mind is of immense value in the ordinary business of life, as its power of discrimination, when properly directed, is sure to detect error, and establish upon a sounder basis the professed and undeviating principles of truth.

It will not be necessary to remind you that at the commencement of this address I noticed that among other qualities of the mind was the power of *observation* as exercised through the sense of sight. This function of the intellect cannot be imparted by any distinct branch of teaching; but the observing student is never at a loss if he keeps his eyes open to the beauties of nature, and that large field which is ever present for its useful and healthy exercise. On any subject that comes before us it is necessary to be observant, as it stores the mind with ideas, and gives to every object its due and perfect proportions. It, moreover, improves the taste, enlarges the mind, and furnishes a more perfect conception of figure, and of those symmetrical laws by which we are enabled to judge of the beauty and harmony of the works of nature and of art. These are some of the benefits which may be derived from observation, but this quality of the mind is not confined to the sense of sight; on the contrary it has a much wider range, as a man of observant powers will

perceive beauties and detect errors with much greater facility from descriptions of what he hears or reads, than those whose faculty of observation is not properly exercised. In conversation, how profitable it is to obtain a clear conception of the ideas of the speaker, and to be able, from observation, to collect that which is useful and reject what may be trivial or unimportant! In every transaction connected with society, it is of great importance to be able to discriminate with impartiality on the views and opinions of others.

These are the uses to which, in my opinion, we should apply our thoughts in study, and, provided it is done with an earnest desire after truth, we may reasonably conclude that we have used and not abused the faculties which, in common with all mankind, we have received at the hands of Infinite Wisdom.

In conclusion, I have to thank you for the patience with which you have listened to these remarks. I can only hope they may be serviceable to your valuable institution, and I do sincerely trust that the junior members will not forget that a cultivated mind, an untiring industry, and a high sense of honour are the true and only legitimate paths to distinction.

LECTURE V.

ON FIRST PRINCIPLES, AND THE THICKNESS OF THE EARTH'S CRUST EXPERIMENTALLY CONSIDERED.*

To a careful observer, and to every thinking mind, there cannot exist a doubt as to the intention of the Creator in ordaining that everything in existence, from the heavenly bodies which move in space down to the most minute molecule of matter, should be subjected to fixed and definite laws. I need not inform you upon what principle the sun, the fixed stars, and the planetary system revolve in their orbits, and with what exactitude, in regard to time and space, they perform their respective diurnal and orbitual motions—all of them tending to one great end, demonstrating as they roll the power and wisdom of their Creator, through the laws by which they are governed. In illustration of that power, and the knowledge which it teaches, I may perhaps be permitted to notice a few astronomical and physical facts, which for ages have come under the notice of the philosopher, and which have engaged some of the most powerful minds that have existed since the days of Bacon, Galileo, and Newton. It is interesting to trace the discoveries and developments of these great men, and to watch the progress of astronomical knowledge in our own day. Much has been done by the two Herschels, Adams, and the Astronomer Royal, and much yet remains to be accomplished before we are fully acquainted

* Delivered to the members of the Literary and Philosophical Society of Newcastle-on-Tyne.

with the composition of the sun and the planets of the Solar System. Let us, for a few moments, endeavour to ascertain under what cosmical conditions modern astronomers have found the great central luminary of the Solar System. Many theories have been raised, some abandoned, and some confirmed; but all are agreed that it is the great fountain of heat, the vivifying, germinating principle of nature; and, moreover, that our own globe, and the surrounding planets and their satellites, depend upon its influence for that degree of temperature which appears to constitute the principle and maintenance of animal and vegetable existence. How wonderful! how extraordinary! and how important are the conditions by which our lives are supported! The surface of our earth is animated into active existence by the rays of the sun. Every atom of matter teems with life, and to what depth this great principle extends yet remains a question for the human mind to discover. We have the facts of animated existence before our eyes. We find at great depths in mines the remains of animal and vegetable life, and in sedimentary deposits we have abundant evidence of its past existence. It is visible at the greatest depths of the ocean; and, judging from analogy, I may venture to state what is more than probable—that it exists at the very core and centre of the earth.

This vast and interminable measure of life may be traced to the laws by which it is governed, by which it is preserved, by which it runs the cycle of its existence, and by which it ultimately makes way for a new succession of the animated principle performing the same functions, and that for ages immeasurable by time and, as far as human intellect can discover, infinite in duration.

If we examine more closely those laws by which the unerring functions of nature are performed, and by which we receive and maintain life, we shall find much

to admire and everything to approve. They left the hands of the Great Architect of Nature perfect: by them we are supported in every good and useful work, and from them we cannot swerve with impunity. To the sun we have alluded as the great source of heat, and the living principle on which the animal and vegetable kingdoms depend; and it may be interesting and useful for us to examine, as far as our knowledge extends, into the composition and properties of this great luminary, by which the fecundity of this world and the surrounding planets are maintained.

It has been ascertained, from observations on the sun's horizontal parallax, that it is situated from us at a mean distance of 91,000,000 miles; and it is not surprising that, at such a distance, the sun should appear so small, that it should so powerfully influence our condition by its heat and light, and that it should give us such high conceptions of its magnitude and the important processes that are carried on within it. As to its actual magnitude we can be at no loss, knowing its distance and the angles under which its diameter appears to us. An object of this immense magnitude, placed at a distance of 91,000,000 miles and subtending an angle of 32′ 4·2″, gives for its real diameter 882,000 miles. Such we may consider the bulk of this stupendous globe; and provided we compare it with what we have already ascertained of the dimensions of our own planet, we shall find, according to Sir John Herschel, that, in linear magnitude, it exceeds the earth in the ratio of 111·5 : 1, and in bulk as 1,384,472 : 1.*

* In order to give a clearer conception of the relative masses and distances of the sun and planets composing our system, Sir John Herschel supposes that on a level green field a globe 2 feet in diameter is placed; this will represent the Sun, and Mercury would then be proportionally represented by a grain of mustard-seed, revolving in a circle 164 feet in diameter; our Earth would be represented by a pea revolving in a circle of 430 feet in diameter, and so on for the masses of Jupiter and Saturn, which would

It has been calculated that the masses of the planets which have satellites—namely, the Earth, Jupiter, Saturn, Uranus, and Neptune—are: taking the Earth as 1, the Sun is 354,936; Jupiter, 338·475; Saturn, 101·066; Uranus, 14·255; and Neptune, 18·9. From these calculations may be derived the densities of all these bodies as follows:—Seen from a distance equal to the mean radius of the Earth's orbit, the diameter of the Sun would subtend an angle of 1,914″; that of the Earth, 17·4″; Jupiter, 186·6″; Saturn, 177·7″; Uranus, 74″; and Neptune, 81″. Their real diameters are, therefore, in the proportion of these numbers, and the bulk in proportion of the cubes. By dividing the quantities of matter by the bulks we have the densities: if that of the Earth be 5·67 (water being 1), we have for—

The Sun	1·47
The Earth	5·67
Jupiter	1·36
Saturn	0·74
Uranus	0·97
Neptune	1·02

Speaking of the motion of the sun and planets, Sir John Herschel, in his treatise on Astronomy, says: 'It is hardly possible to avoid associating our conception of an object of definite globular figure, and of such enormous dimensions, with some corresponding attribute of massiveness and material solidity. That the sun is not a mere phantom, but a body having its own peculiar structure and economy, our telescopes distinctly inform us. They show us dark spots on its surface, which slowly change their places and

represent good-sized billiard-balls; and Neptune, the most distant planet, would figure as a moderately-sized plum, revolving in a circle of 2½ miles in diameter. These are, however, nothing when compared with the distances of the fixed stars, which are so vast as to be almost inconceivable. Lord Wrottesley makes their distance, for a parallax of 1″, equal 19,788,239,343,000 miles

forms, and by attending to whose situation, at different times, astronomers have ascertained that the sun revolves about an axis, inclined at a constant angle of 82° 40′ to the plane of the ecliptic, performing one rotation in a period of 25 days, and in the same direction with the diurnal rotation of the earth—*i.e.*, from west to east. Here, then, we have an analogy with our own globe; the slower and more majestic movement only corresponding with the greater dimensions of the machinery, and impressing us with the prevalence of similar mechanical laws, and of, at least, such a community of nature as the existence of inertia and obedience to force may indicate. Now, in the same proportion by which we invest our idea of this immense bulk with the attribute of inertia, or weight, it becomes difficult to conceive its circulation round so comparatively small a body as the earth, without, on the one hand, dragging it along, and displacing it, if bound to it by some invisible tie; or, on the other hand, if not so held to it, pursuing its course through space, and leaving the earth behind. If we tie two stones together by a string, and fling them aloft, we see them circulate about a point between them, which is their common centre of gravity; but if one of them be greatly more ponderous than the other, this common centre will be proportionally nearer to that one, and even within its surface; so that the smaller one will circulate, in fact, about the larger, which will be comparatively but little disturbed from its place.

Whether the earth moves round the sun, the sun round the earth, or both round their common centre of gravity, will make no difference, as far as appearances are concerned, provided the stars be supposed sufficiently distant to undergo no sensibly apparent *parallactic* displacement by the motion so attributed to the earth; and from the almost immeasurable amount of such displacement, we conclude that the scale of the sidereal universe is so great,

that the mutual orbit of the earth and sun may be regarded as an almost imperceptible point in its comparison. Admitting then, in conformity with the laws of dynamics, that two bodies connected with and revolving about each other in free space do, in fact, revolve about their common centre of gravity, which remains immoveable by their mutual action, it becomes a matter of further enquiry whereabouts between them this centre is situated. Mechanics teaches us that its place will divide their mutual distance in the inverse ratio of their weights or masses; and calculations inform us that this ratio is as 354,936 : 1 —the sun being in that proportion more ponderous than the earth. From this it will follow that the common point about which they both circulate is only 267 miles from the sun's centre, or about $\frac{1}{3300}$th of its own diameter.

Here, it will be observed, is a beautiful illustration of mechanical philosophy, which teaches volumes, and gives us an insight into those laws of gravitation and propulsion by which two bodies, of so much weight and so disproportioned to each other in magnitude, are so nicely balanced as to cause the earth to revolve in its orbit, imperceptible to its inhabitants, at a velocity of about 1,136 miles per minute, equivalent to the immense velocity of 68,160 miles per hour!

It would occupy too much of your time to proceed further with this subject; my object in these statements being to show (according to Newton) the mechanism by which these masses are regulated in their orbits, by an attracting force which varies directly as the mass and inversely as the square of the distance. These wonderful achievements of the Great Author of Nature teach us lessons of humility as well as of mechanics; and our successors, for ages to come, may draw from them conclusions which, founded on natural laws, confirm the only true philosophy by which the human mind and the

human heart should be guided. I must not leave this part of the subject without noticing some recent discoveries, said to exist in the spots on the sun's disc. Sir William Armstrong, in his address to the meeting of the British Association, notices Mr. Nasmyth's discoveries of willow-leaves 1,000 miles long and 100 miles broad, which apparently interlace themselves over the luminous surface, and fringe the edges of large cavities which appear to penetrate the exterior envelope to immense depths. These extraordinary appearances may require further investigation: for the present they are interesting, and it is to be hoped that more extended inquiries may lead to further discoveries.

Having thus glanced, however imperfectly, at the laws which philosophers of the past and present age have demonstrated as belonging to the system of the universe, let us now direct our attention from celestial phenomena to some of the numerous truths which present themselves to our notice in the physical condition of the globe which we inhabit. It has been shown that the earth's equatorial diameter is 7,925·648 miles, and its polar diameter 7,899·17 miles, making a difference of 26·478 miles. From this difference it is obvious that the form of the earth's section, through the axis, is an ellipse, and the outside figure that of an oblate spheroid; and this departure from a true sphere has been proved to arise from the centrifugal force which is generated in the equatorial regions by its revolution round its axis in twenty-four hours. As the earth thus revolves round an axis passing through the poles, the equatorial portion of its surface has the greatest velocity of rotation; consequently, the velocity of the other parts diminishes in the ratio of the radii of the circles of latitude as they approach the poles; and here we have the theory of centrifugal action, which gives to the earth its flattened form at the poles.

Irrespective of the physical conditions under which the earth is placed as regards the surrounding planets, it may be interesting shortly to examine :—

1st. The envelope of atmosphere by which it is surrounded.

2ndly. The waters of the ocean which rest in the cavities of its surface.

3rdly. Its geological formation ; and

Lastly. Its central heat, the thickness of its crust, &c.

When we ascend to any considerable height, either in a balloon or to the top of a mountain, we are made aware of the elevation we have attained by uneasy sensations, arising from a deficient supply of air. At an altitude of 10,800 feet, about the height of Mount Etna, we have left under our feet about one-third of the whole mass of the atmosphere, and at 18,000 feet we have ascended through one-half the ponderable body of air. Hence follows the difficulty of respiration, as experienced by MM. Biot and Gay-Lussac at an elevation of 25,000 feet. The same sensations, and those more severe, were experienced by our own distinguished aëronaut, Mr. Glaisher, at a higher altitude ; and from this it is easy to conceive that in rising we continually get above the denser portions of the atmosphere, which varies not as the height, but in a constantly-decreasing ratio. We may infer, therefore, from our knowledge of the mechanical laws which regulate the dilatation and compression of elastic fluids, that at an altitude of $\frac{1}{100}$th part of the earth's diameter the tenuity of the atmosphere (if it at all exists at that height) must be equally fatal to animal life and to combustion. But, leaving out of consideration the unknown limits or thickness of the atmosphere, we may reasonably conclude that it does not exist at an altitude of eighty miles.

It is said—with what truth it is not for me to determine—that nature abhors a vacuum; and yet, according to what we have stated, we reach that point at eighty miles' elevation, where we are supposed to be entirely free of the atmospheric envelope, and clearly launched into the ocean of space. Supposing this to be true, and that the atmosphere terminates at the height above-named, you will naturally ask, what comes next?—what is there beyond it? The simple answer is, Space. Now, it is evident that to this vast and interminable ocean our imperfect conceptions are unable to form anything like magnitude, either as regards length, breadth, or depth; and we are utterly lost when we attempt to measure it in regard to figure, form, or extent. It is infinite in dimensions, as the dwelling-place of innumerable suns, planets, and satellites: all of them floating, rolling, and moving apparently without order or design, but united by invisible ties, which govern the whole with perfect harmony, and display the same Omnipotent Power and Omniscient Wisdom as those by which they were created, and launched with revolving certainty into the immensity of space.

When we contemplate this boundless ocean, and the myriads of suns and planets by which it is peopled, we are overcome with feelings of astonishment and admiration, whilst our little earth sinks into insignificance when compared with the distance, number, and magnitude of those bodies which exist in our own system. I have sometimes, in meditating on this subject, compared space to an immeasurable vessel, containing a fluid of great tenuity, filled with animalculæ, floating and in motion in every direction, which to mortal eyes appear a chaos of confusion, but yet in such perfect harmony with each other's motions as to prevent collision, and maintain the integrity of definite laws established for their guidance. It is

apparently so with ourselves and the other myriads of inhabitants in space; and my only guide to this conclusion is, that there must be some highly-rarefied fluid of such extreme subtilty, that it becomes the medium through which light and heat are transmitted from the great luminary in the centre of our system to the remote and unknown regions of space by which we are surrounded. I offer these opinions with considerable diffidence, and shall be glad to find them confirmed by the researches of the astronomer and the mathematician.

The ocean covers about two-thirds of the earth's surface, and, together with the atmosphere, present to the mind of the philosopher an inexhaustible subject for contemplation. Its extent, depth, magnitude, currents, temperature, and economy, are all questions of deep interest to those acquainted with the laws, and the principles on which it is maintained in the full integrity of purpose and purity of condition. Its saline properties and combinations preserve it uncontaminated, and fit it, in all its pristine purity, for the purposes for which it was intended. Such are its admirable properties, that I am sure you will excuse me if I endeavour to show how important it is to the economy of nature, and the maintenance and preservation of life.

First, then, we depend upon the sea for our existence; by it we are supplied with food and all the necessaries of life. Without the sea we should have no rain, dew, or rivers; and without these exhalations we should have no clouds—everything would become arid and dry, and the surface of the earth would be burnt to a cinder. In this and other countries we should be deprived of that warm covering which shelters us from the intensity of the sun's rays—that soft curtain of clouds and genial warmth so invaluable to the health and comfort of the inhabitants of these islands. We too often complain of the climate and mois-

ture by which this country is surrounded; but where is there another country so healthy, so fruitful, and so abundant in its productions—latitudes and all other conditions considered? You may depend upon it those complaints are groundless, and I for one would be sorry to witness any diminution of the benefits which we derive from the ocean in all its elementary conditions, as applied to climate and the wants of human existence.

Captain Maury—in his excellent work on the 'Geography of the Sea'—in contrasting the sea and the atmosphere, says 'that the weight of the atmosphere is equal to that of a solid globe of lead sixty miles in diameter. Its principal elements are oxygen and nitrogen gases, with a vast quantity of water suspended in them, in the shape of vapour. In common with all substances, the ocean and the air are increased in bulk, and consequently diminished in weight, by heat; like all fluids, they are mobile, tending to extend themselves equally in all directions, and to fill up depressions wherever vacant space will admit them; hence in these respects the resemblance betwixt their movements. Water is not compressible nor elastic, and it may be solidified into ice, or vaporised into steam: the air is elastic; it may be condensed to any extent by pressure, or expanded to an infinite degree of tenuity by pressure being removed from it; it is not liable to undergo any change in its constitution, beyond these, by any of the ordinary influences by which it is affected.'

Such are the views of one of our first meteorologists; his facts are few and simple. But there are other characteristics peculiar to the sea, as the abode of animated and vegetable life. Like the earth and the atmosphere, it is fruitful in its provision for innumerable families of animated existence that live and die within its territory,

and to which we are indebted for an abundant and nourishing article of food. Like the other domains of nature, it teems with life; and we should be ungrateful to an Allwise Providence if we failed to appreciate the immensity of its value, in conjunction with the atmosphere, as the great laboratory of nature, from which we derive so many benefits.

But the sea without the atmosphere would become a stagnant lake; and here again we have calls on our admiration in the economy with which every phenomena of nature is conducted, and the uses for which they are intended. To the atmosphere I therefore invite your attention, as the grand co-operator with the sister element of water, in producing that combination which carries on its wings the vapours of the ocean, and distributes them in refreshing showers over the parched surface of the earth. From this again it returns—after having performed its function in the support of animal and vegetable life—in the shape of springs, brooks, and rivers, to the ocean from which it was extracted. Thus uninterruptedly goes on this beautiful process of evaporation, diffusion, and condensation, so admirably adapted in the economy of nature for the maintenance and support of every living thing!

Independently of the laws by which the meteorologist is enabled to form his opinion, there are other processes, no less interesting, which belong exclusively to the atmosphere and the sea: the first as the propeller, and the second as the liquid pathway, by which we are enabled to communicate with distant countries, and maintain upon its surface fleets and flotillas—the great connecting links of commerce, and the means of intercourse between foreign nations. Such are the marvellous powers of air and sea, and such are the effects of the obedient waters as they descend from the mountain-tops to the sea, and are

again returned at the right time and in proper quantity to fertilise the earth! In the ocean itself we have monuments of its power in the abrasion of rocks, as their fragments are fashioned into boulders, pebbles, and shingle, and the very sands on the seashore pronounce the triturating and enduring power of water.

The waters of the ocean appear, in conjunction with subterranean action, to act an important part in the formation of the earth's surface. Sir John Herschel states that 'the sea is constantly beating on the land, grinding it down, and scattering its worn-off particles and fragments in the state of mud and pebbles over its bed.' Geology affords abundant proofs that existing continents have more than once been destroyed, torn to pieces, submerged, and reconstructed according to the nature of the alternate forces of oceanal disintegration and volcanic action.

The phenomena of elevation immediately resulting from the action of subterranean forces are curious and interesting, and to them—in conjunction with running water—we owe all the variety of forms of mountain, hill and dale, which mark the beauty and constitute the gracefully-undulating surface of the globe. The absence of anything like order, system, and arrangement would almost indicate a want of any known principle of action; but I believe the more minute researches of geologists have discovered distinct approximation to general laws in the dislocation of strata, and the upheaving and subsidence of the mountain districts. These, with the abrasions of the harder strata by rivers and mountain-torrents, will account for the diversity of hill and dale which is so strikingly apparent on the earth's surface.

For a great many years it has been an interesting subject of inquiry amongst physical geologists as to the state of the interior of our planet, and the high temperature

that is supposed to exist at great depths under the surface. The terrestrial temperature, at a depth of from 80 to 100 feet, is not affected by the changes of the seasons, but remains constant throughout the year; and a series of experiments, of which I availed myself during the sinking of one of the deepest coal-mines in this country—that of Dukinfield, near Manchester, which is about 2,100 feet, or upwards of 250 fathoms—gives the following results, viz.: The amount of increase indicated by these experiments is from 51° to 57° 40′, from a depth of 20 to 693 feet below the surface, or 1° in 99 feet; but if we take the results which are more reliable, namely, those between 693 and 2,055 feet, we have an increase of temperature from 57° 40′ to 75° 30′ Fahr., or a mean increase of 1° in 76·8 feet. This rate of increase is not widely different from that obtained by other authorities, such as Walfeoden and Arago, who found an increase of 1° in 59 feet: other experiments have given an increase of 1° in 71 feet.

In one respect the observations recorded in the Dukinfield mine are particularly interesting, as they give the temperature from carefully-constructed instruments of various descriptions of rocks; and appear to prove, what had hitherto been suspected, that the conducting power of the rocks exercises considerable influence on the temperature of the overlying strata, which accounts for the difference in the increase of temperature at different depths. However this may be, it is evident that the increase of temperature is proportional to the depth, being at the rate of 1° Fahr. for every 60 or 70 feet.

If we assume the rate of increase to be continued to a depth of nearly three miles, we arrive at the temperature of boiling-water; at thirty-nine miles, we attain an amount of heat equivalent to 3,000°, which would melt the hardest rocks. At such a high temperature, and at

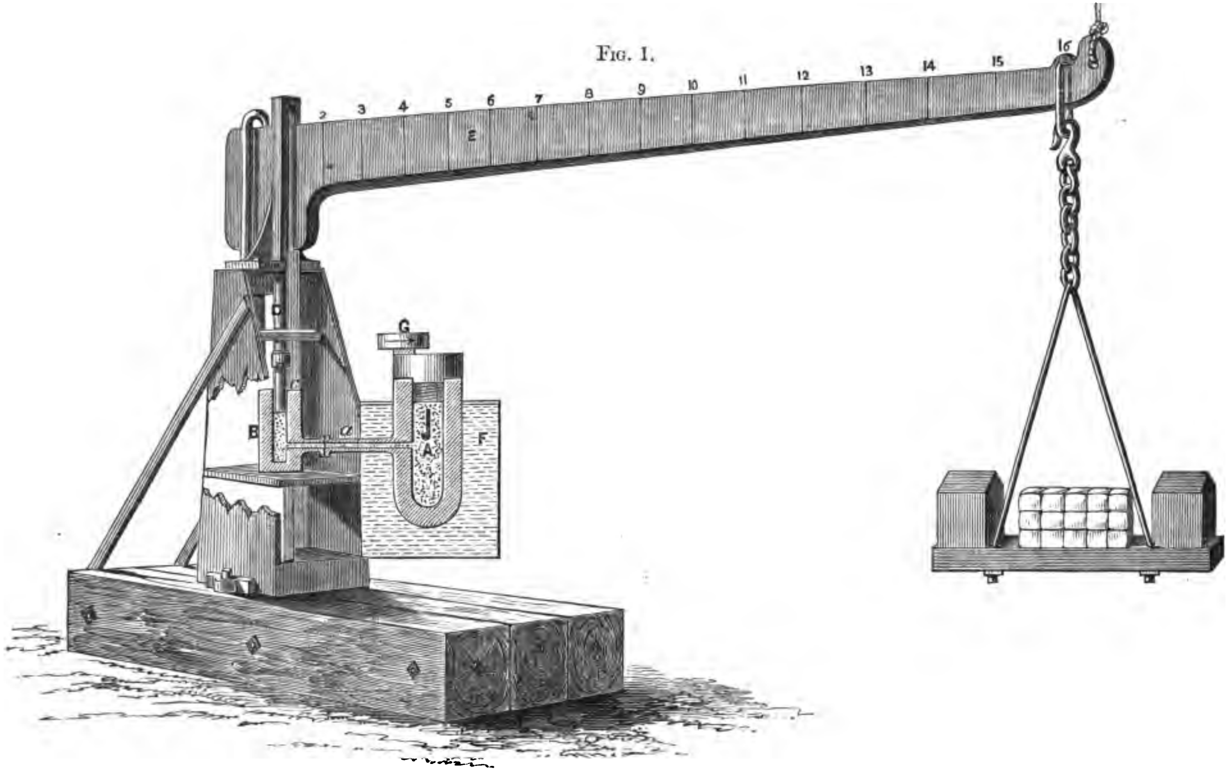
such a depth, we would naturally infer, from the foregoing, that the whole material of the earth, at and below that point, would be in a fluid state, and this would doubtless be the case under the ordinary pressure of the atmosphere; but at that depth we have to take into account the weight of the superincumbent mass, as it presses on the fluid or semifluid matter below.

It has always been a question of interest to geologists to ascertain the thickness of the earth's crust, or at what depth under the surface it becomes fluid. To determine, or rather to approximate, the solution of this question, my friend Mr. Hopkins of Cambridge, Dr. Joule, and myself were requested by the British Association to institute a series of experiments on pressure, and the conductivity of the different strata with which we are acquainted. This very interesting inquiry has extended over a series of seven to eight years, and the results obtained are of that nature which, I trust, will justify me in bringing the subject before you. The whole of the experiments have been carried on at my works in Manchester, having at the time a powerful apparatus, as shown in fig. 1.

A is a strong cylinder of brass, with a branch *a* communicating with the cylinder B, into which works a steel plunger *c*, which fits into the socket in the bar D. On the top of this bar the powerful lever E is applied, which, pressing on the liquid in the cylinder B, forces it through the bore of the pipe *a* (on the principle of the Bramah press), and by which nearly any amount of pressure may be attained. On the top of the cap of the cylinder A, which is made air and water-tight, and inserted in the bath F, a mariner's-compass G is placed, the use of which we shall presently describe.

Having adjusted the apparatus, and filled the cylinder A with the material to be experimented upon, a charcoal-

Fig. I.



fire is lighted under the bath, and before applying the lever the point of fluidity is ascertained. This was accomplished with great difficulty in the first instance, as we had no means of ascertaining the melting-point with anything like accuracy, until Professor W. Thomson of Glasgow, who happened to be present at one of the experiments, suggested the mariner's-compass, and the introduction of a magnetic needle into the substance, which answered the purpose admirably. This ingenious application was effected by inserting the magnetic needle into the solid mass to be experimented upon: and having brought the needle of the compass within its influence, it pointed directly over the centre of the cylinder, and was retained in that position so long as the material was in the solid state; but the instant the melting-point was arrived at, by increasing the temperature of the bath, the needle, no longer supported in the solid substance, dropped through the fluid to the bottom of the cylinder. The instant that was accomplished, the needle of the compass, being no longer influenced by local attraction, turned round to the pole. From this arrangement it will be seen that the temperature of fluidity was carefully and accurately determined.

Let us now consider by what means the experiments were calculated to determine the depth at which it was supposed the solid crust of the earth becomes fluid. We have already shown that the temperature increases in the ratio of the depth as we penetrate below the earth's surface; and, having ascertained the melting-point of any solid body at the pressure of the atmosphere, we had then to determine, by the apparatus just described, the effect that greatly-increased pressure had upon the material at different degrees of temperature. For this purpose we commenced with substances such as spermaceti, bismuth, &c., which melt at a low temperature; and, by means of

the large lever, we indicated *an increase in the temperature of fusion proportional to the pressure to which the fused mass was subjected.* It was further ascertained that a pressure of about 15,000 lbs. on the square inch indicated an increase in the temperature of fusion of less than 30°, or about one-fifth of the temperature at which they melt under the pressure of the atmosphere.

Subsequent experiments show that, for every 500-lbs. pressure per square inch, the temperature of fusion is raised 1°; but this law of increase leaves out of consideration the conducting powers of substances when solidified under pressure, and it has been left to Mr. Hopkins to show that those powers are materially increased by pressure—as also that the densities, strengths, and general molecular structure of bodies are influenced, in some given ratio, by the amount of pressure applied.

All these conditions tend to increase the solid thickness of the earth's crust, and we may venture to state that, at a depth of 100 miles, we should find a pressure equal to 1,200,000 lbs., or nearly 600 tons on the square inch. With this enormous force, according to the ratio of increase of 1° for every 500 lbs., we have an increase of temperature equivalent to 2,600°; and taking 2,000° for the temperature of fusion under the pressure of the atmosphere, it would then require 4,600° Fahr. as the required point of liquefaction at that depth.

Reasoning from these facts, we came to the conclusion that the earth's nucleus, under the enormous pressure to which it is subjected, may not be fluid but solid, or probably in the semifluid state, so as to allow free motion of the particles, with a proportionate increase of temperature due to the pressure above the atmospheric point of fusion. In this calculation we have not taken into account, as before stated, the conductivity of the superincumbent mass pressing upon the nucleus. This question is still

under the consideration of Mr. Hopkins, and we are encouraged to look forward with great interest to its solution.

To show the effect of great pressure on a variety of substances, I may here mention that I availed myself of the apparatus constructed for Mr. Hopkins' experiments to subject different materials to a pressure of from 90,000 to 124,000 lbs. per square inch, equivalent to 8,266 atmospheres, or a column of water 51½ miles in height; and as these experiments are of great interest, I may venture in this place to introduce them to your notice. They were made on dried clay, dry charcoal, gunpowder, and on different kinds of timber. In the first series of experiments we were greatly limited as regards the amount of pressure employed; the cylinder being 3 inches diameter gave only from 5,000 to 6,000 lbs. pressure per square inch. This was, however, reduced to 1¼ inch, and ultimately a steel cylinder, ¾ of an inch in diameter, was used, from which the following results were obtained:—

TABLE SHOWING THE EFFECTS OF COMPRESSION ON DIFFERENT MATERIALS.

No. of Exp.	Description of substance.	Diameter of cylinder in inches.	Weight laid on in pounds.	Pressure per sq. in. in pounds.	Increased density.	Remarks.
5	Dried Clay.	1¼	97,588	79,527	1·164	Mean 1·622.
5	" "	"	97,588	79,527	2·081	
5	Soot.	"	97,588	79,527	1·702	
3	Dried Clay.	¾	54,580	123,507		With this pressure the Cylinder burst.
6	" "	"	47,860	108,526	0·726	This weight was left on for a period of 43 hours.
8	Bees Wax.	"	54,998	124,990	0·642	
18	Block Tin.	"	54,868	124,224	0·800	
	Gunpowder.	"	83,252	67,844	1·320	

The beeswax and block-tin were solidified under pres-

sure, or, more clearly, they were first melted and the pressure applied in the fluid state, and ultimately allowed to cool and become solid under that pressure. Great difficulty was, however, experienced in getting the specimens out of the cylinders, although steel plugs were screwed into the cylinder-bottom for that purpose. The gunpowder, however, was an exception, as it did not adhere with the same tenacity to the sides of the cylinder, and was therefore extracted in the form of a cylindrical bar, with a smooth polished surface, as if turned in a lathe. There were six different kinds of gunpowder obtained for these experiments from the Woolwich Arsenal: most of them were coarsely granulated, but when they came from the cylinder under pressure the granules were so minute as scarcely to be seen under the microscope, and the density so much increased as to have more the appearance of steel than of gunpowder. Some of our military friends were afraid of explosion, from the friction of the granules under pressure; but I apprehended no danger, and I subsequently found that it would not explode; it would not even burn rapidly when held to a candle, but was slowly consumed by throwing off numerous scintillations or incandescent sparks. This was not, however, the case when the consolidated specimens were again granulated and reduced to the state of combustion, as may be seen from the small residue of carbon which was left. These highly-compressed specimens were submitted to Mr. Abel, the government chemist at Woolwich, for analysis; but he found little or no difference in the specific gravity from the ordinary press-cake, the increase being the difference between 1·9353 and 1·9290, equal to ·0063. He also determined the amount of charcoal contained in the residue, after combustion, to be as follows:—

The residue from	480 grains	of No.	I	contained	2·24	grains of charcoal.
,,	,,	,,	II	,,	1·84	,,
,,	,,	,,	III	,,	1·81	,,
,,	,,	,,	IV	,,	1·68	,,
,,	,,	,,	V	,,	2·04	,,
,,	,,	,,	VI	,,	1·96	,,
				Mean	1·93	Nearly.

These results certainly indicate that the increased pressure promotes the complete action of the constituents of powder upon one another; as a considerable amount of effect is lost by incomplete contact of the particles, which is the case where it escapes ignition in the ordinary pressed powder when fired from a gun. These facts are the more remarkable if we compare the residues from the same powder, granulated from the press-cake, which was found, as the mean of the whole six samples before, to be 39·143 grains, or in the ratio of 1·93 : 39·14, or about 1 : 20 in favour of the highly-compressed powder. From this it may be safely inferred that the explosive force of gunpowder is considerably increased by pressure; and it may be of importance to know to what extent gunpowder can be compressed to attain effective combustion, and the maximum of explosive force.

Permit me, before I sit down, to bring under your notice what I have already stated in another place on the new theory of heat, which proposes to explain the thermal agency by which power is produced, and to determine the numerical relations between the quantity of heat and the quantity of mechanical effect produced by it—now termed 'The dynamical theory of heat.' Carnot wrote on this subject: his theory rested on the abstract conception of a perfect thermo-dynamic engine, or two propositions, which suppose, first, if a quantity of heat enters a body by any process, and changes its temperature and physical state, and it being again restored to its primitive condition, it then follows, according to Carnot's second proposition, that the quantity of heat which passes

out of the body is precisely the same as that which passes into it. This view, to some extent, may be correct; but it does not recognise the principle of heat being lost by conversion, according to the new theory of my friend Dr. Joule, who maintains that heat may be changed by conversion into mechanical effect. To elucidate this distinction—as it is put by Mr. Hopkins—suppose a quantity of water to be poured into a vessel. It might then be asserted that in emptying the vessel again we must pour out just as much water as we had previously put in. This would be equivalent to Carnot's theory with respect to heat. But suppose a part of the water while in the vessel to be converted into vapour, then it would not be true that in emptying the vessel the same quantity of water (in the form of water) must pass out of the vessel as had before passed into it, since a portion would have passed out in the form of vapour.

On this the new theory of heat is founded, as it not only asserts, generally, the convertibility of heat into mechanical effect, and the converse; but it goes further, by maintaining that whether heat be employed to produce mechanical force, or mechanical force to produce heat, the result is similar—viz., the same quantity of the one is equivalent to the same quantity of the other.

It was reserved for Dr. Joule to lay the foundation of this theory, by a series of experiments to determine the law of equivalents; and in whatever way he employed force to produce heat, he found the same approximate quantity of heat to produce the same amount of mechanical force. This force he estimated in foot-pounds—namely, that the introduction of 1° of heat into 1 lb. of water is equivalent to 772 lbs. raised to a height of one foot. From these researches is derived the Law of Equivalents, now in general use as the measure of work done by the application of any description of mechanical force.

LECTURE VI.

IRON AND ITS APPLIANCES.*

IT requires no great depth of research to discover the time when iron first came into use in aid of our manufacturing industry. It is almost within the recollection of the present generation, and we may safely date its application to the discoveries of Watt and Arkwright. Its extensive use may date from the commencement of the present century, or, more accurately, from the close of the war in 1815, when a new era burst upon the country in the cultivation of the arts of peace. From that time to the present there has been a continuous and amazing increase—an increase unparalleled in the history of nations, and without example, as regards extent, in its varied forms of application to constructive art. It must be in the recollection of many persons now living, how very imperfect our machines and mechanical contrivances were as late as 1820. At that time the steam-engine had certainly attained a tangible shape in being composed entirely of iron, and millwork was just emerging from the state in which it was left by Smeaton and Rennie. Both of these engineers had introduced improvements, by substituting to some extent iron for wood; and the latter, in his construction of the Albion Mills, was the first to supplant the old wooden wheels by the more compact and ingenious constructions of cast-iron. Smeaton and Rennie

* Delivered to the members of the Literary and Philosophical Society of Newcastle-on-Tyne.

may therefore be considered the pioneers of iron appliances. In their time little was done; but it may, nevertheless, be interesting for us to follow this invaluable material through the different stages of its utility, and treat of its appliance—

1st. To the Steam-engine;

2nd. To Millwork; and

3rd. To Machinery: noticing the varied forms and conditions in which it is employed for security on the one hand, and its economical distribution for the purposes of construction on the other. In these topics will be found sufficient to engage our attention for the evening.

It must be borne in mind that in every construction, whether it be a house, a ship, a boiler, or a bridge, the architect or engineer is supposed to be conversant with the mechanical and chemical properties of the material he employs. Assuming this to be the case, we have then to consider, in treating of the first division of our subject—the Steam-engine—what are the strains to which its different parts are subjected, and what rules we ought to follow to attain a maximum result. Let us, for example, take the boiler, and we shall find, in that alone, considerations of deep importance, as regards its construction, and the quality of the material of which it is composed. Now, with respect to its security, durability, and economy, we have to consider the nature of the forces which act upon its interior surface; and from these we have to construct a vessel which, in material and workmanship, presents its maximum powers of resistance. These are the requisites and the responsibilities which the engineer incurs in constructions of this kind; and in order to arrive at the required data, and the necessary skill for the due and perfect performance of such a duty, it is evident that they should not be entrusted to the head and hands of

the ignorant and uninformed. To make a sound and perfect boiler—or as near perfection as possible—we have to take into account the working-pressure of the steam and the best forms necessary to resist that pressure, to arrive at the maximum of safety. These and other considerations—such as the riveted joints, position and forms of flues, &c.—are necessary to be taken into account in order to prevent explosion and collapse.*

In a previous communication I pointed out that the cylindrical boiler is the only one calculated to resist the elastic force of steam, and that the greatest care is necessary to be observed, not only as regards the strength of the plates—which should be of the best quality, equal to a tensile strain of twenty-one tons per square inch—but they should be double-riveted, if we are to have a perfectly strong and well-constructed boiler. But before entering upon the art of construction, allow me to direct your attention to some of the properties of steam, as regards its temperature, pressure, volume, and density; and we shall then have a better conception of the forces with which we have to deal, and how to regulate these forces, and construct vessels to retain them without risk to property or any of those casualties which endanger life.

* *Vide* 'Useful Information for Engineers,' 1st series, 4th edition, p. 28.

TABLE I.

TABLE OF TEMPERATURES, VOLUMES, PRESSURE, ETC.

Pressure per square inch in pounds		Corresponding temperature of Fahrenheit	Relative volume of steam compared to volume of water that produced it
Below the Atmosphere	1	102·9	20954
	5	161·4	4624
	10	192·4	2427
	15	213·0	1669
Above the Atmosphere	1	216·4	1572
	5	228·3	1280
	10	240·7	1042
	15	251·2	882
	20	260·3	765
	25	268·9	677
	30	275·7	608
	50	299·1	434
	70	317·8	340
	90	332·2	281
	105	343·3	249
	135	360·8	203
	165	375·6	173
	180	382·3	161
	210	394·6	141
	225	400·2	133

Now, as these forces have to be retained within comparatively small limits, we must endeavour to ascertain the force which tends to rupture a cylindrical boiler in the direction of its axis, or to separate the ends from the sides. To accomplish this we have only to multiply the area of the ends, in inches, by the number of units of force applied to each superficial inch, and the result is the total divellent force in that direction. To resist this force, we have to ascertain the area or number of square inches of the plates in the circumference, as the resistant, which, acting by tension in a longitudinal direction, will retain the ends in their places so long as the strength of the iron or of the riveted joints exceeds that of the internal force, or until the moment of rupture, when they become

equal. Let us, for example, suppose a boiler, six feet in diameter and thirty feet long, to be composed of ⅜-inch plates, whose ultimate strength is twenty-one tons per square inch, and we have, with steam of sixty pounds pressure, a force against each end of the boiler of 244,290lbs. = 109 tons. To this force we have a resistance equivalent to the areas of the plates, $84{\cdot}75 \times 21 = 1779{\cdot}75$ tons, which gives a large margin of strength, being in the ratio of 1779 : 109, or nearly as 16 : 1.

This excess of strength is evidently great; but I have already shown by direct experiment that we must not calculate upon such a powerful resistance as twenty-one tons per square inch, but must reduce it to the following standard, viz.:—

If we take the ratio of the strength of the plate at 100, we must reduce it for double-riveting to 70, and for single-riveting to 56—so that we have the resistance in the ratio of the numbers 100, 70, and 56. Now, as very few boilers are double-riveted—unless it be locomotives—we come to the standard of 56 instead of 100; and in place of the boiler being equal in its powers of resistance to 1779·75 tons, as given above, it would burst, or the ends would be torn from the sides with 996·6 tons, being in the ratio of 996·6 : 109—or, in other words, it is nine times stronger than the assumed pressure at which it is worked.* This is not, however, the case as regards the curved sides, which have a tendency to rupture along the whole length of the cylinder upon each lineal unit of its diameter. With the forces in the direction calculated to divide the cylinder in halves, the resistance would be represented by multiplying the diameter by the force

* This is clearly the case, and we may calculate the actual resistance by deducting the areas of the rivet-holes, which reduces the area from 84·75 to 47 square inches, which taken, as above, at 21 tons per square inch gives $47 \times 21 = 987$ tons—a near approach to the coefficient of 56 as the ultimate strength of the single-riveted joint.

exerted on each unit of surface, and the product by the length of the cylinder, which gives the divellent force in that direction.

Taking the boiler which we have selected, 30 feet long and 6 feet in diameter, and plates $\frac{3}{8}$-inch thick, and we again have—

$$\frac{72 \times 60 \times 360}{2240} = 694 \text{ tons}$$

as the pressure acting upon both sides of the circumference throughout its whole length.

Now, assuming that the plates with single-riveted joints are equal in their powers of resistance to 34,000 lbs., or about 15 tons per square inch,* we then have according to the above rule $\cdot 375 \times 360 \times 2 \times 15 = 4050$ tons as the force that would burst the boiler. It has, however, been shown that the collective force upon the longitudinal seams is only 694 tons; consequently we have an excess of strength in the ratio of 4050 : 694, or as 6 : 1 nearly. Now this is not too large a margin of security, but it is sufficient, provided the plates and workmanship are of the best quality—otherwise it would be desirable to have thicker plates. To this, however, I have a decided objection, as there is no economy in the use of an inferior material; on the contrary, it is highly injurious as regards the transmission of heat, and the strength of the boiler when composed of an inferior quality of iron cannot be depended upon. In every case of boiler-construction it is essential that we should avoid the introduction of inferior plates, which in general partake more of the crystalline than the ductile character, and are therefore highly objectionable where they have to resist so powerful an agent of destruction as the elastic force of steam.

On this part of the subject I may advert to facts which

* *Vide* 'Useful Information for Engineers,' 1st series, 4th edition, pp. 42 *et seq.*

I have stated before,* that on referring to the comparative merits of the plates composing cylindrical vessels subjected to internal pressure, they will be found in this anomalous condition, that their strength in their longitudinal direction is twice that of the curvilinear direction. This appears by a comparison of the two forces, wherein we have shown that the ends of the 3-feet boiler, at 40 lbs. internal pressure, sustain 360 lbs. of longitudinal strain upon each inch of a plate a quarter of an inch thick—whereas plates of the same thickness have to bear in the curvilinear direction a strain of 720 lbs. This difference of strain is a difficulty not easily overcome, and all that we can accomplish in this case will be to exercise a sound judgment in crossing the joints, sound riveting, and superior workmanship. For the attainment of these objects, the following table, which exhibits the proportionate strength of cylindrical boiler, from three to eight feet in diameter, may be useful :—

TABLE II.

Table of Equal Strengths in the External Shell of Cylindrical Boilers from 3 to 8 feet diameter, showing the Thickness of Metal in each respectively, for a Bursting Pressure of 450 lbs. to the Square Inch.

Diameter of boilers		Bursting pressure equivalent to the ultimate strength of the riveted joint, as deduced from experiment, 34,000 lbs. to the square inch	Thickness of the plates in decimal parts of an inch
ft.	in.		
3	0	450 lbs.	·250
3	6		·291
4	0		·333
4	6		·376
5	0		·416
5	6		·458
6	0		·500
6	6		·541
7	0		·583
7	6		·625
8	0		·666

* *Vide* 'Useful Information for Engineers,' 1st series, 4th edition, pp. 42 *et seq.*

There is another question relating to the strength of boilers which requires careful attention—viz., the internal flues, and their resistance to external pressure. In calculating the strength of boilers, the internal flues, until of late years, were never taken into account. They were always considered much stronger than the exterior shell, and no danger was apprehended from their collapse. Now, in the very face of these conclusions, numerous instances of fatal explosions have occurred, not from the weakness of the boiler itself, but from collapse of the flues, which at a subsequent period were found, from actual experiment, to be the weakest part of the construction.

From the first commencement of boiler-construction to a very recent date, we all of us acted under the impression that the flues were the strongest part of the boiler, and that a perfectly cylindrical tube, when subjected to a uniform pressure, converging upon its axis, was equal in its power of resistance, irrespective of its length. This was, however, an erroneous opinion; as I found, on submitting a series of cylindrical and elliptical tubes to external pressure, that they were weak, and in many cases, in long boilers, they were only one-third or one-fourth the strength of the boiler. This anomalous condition of boiler-construction will account for the numerous accidents that have occurred. It has now been remedied; and deductions from a series of valuable experiments have shown that the resistance of flues or cylindrical tubes, instead of being uniform, follows a totally different law, and gives within certain limits a power of resistance inversely as the length of the tube. These facts led to a very simple and inexpensive process, by which existing flues may be strengthened to almost any degree of tenacity, by the simple introduction or attachment of T-iron or angle-iron hoops at certain distances in the length of the flues.*

* *Vide* 'Philosophical Transactions' for 1867, and 'Useful Information for Engineers,' 2nd series.

From these experiments, I found that the resistance of flues or tubes varies in the inverse ratio of their diameters—inversely as the lengths, and directly as the power of the thickness of the plates: or it may be stated that the strengths decrease in the ratio of the increase of the diameters and the lengths, and increase nearly as the square of the thickness of the plates. The general formula for calculating the strength of wrought-iron tubes is, therefore, where

P = collapsing pressure in pounds.
K = thickness of plates in inches.
L = length of tube in feet.
D = diameter in inches, we have

$$P = 806{,}300 \frac{K^{2.19}}{L\,D}:$$

or it may be calculated by logarithms, in which case it may be written—

$$\text{Log. } P = 1{\cdot}5265 + 2{\cdot}19 \text{ log. } 100\,K - \text{log. } (L\,D).$$

To illustrate this remarkable law: if we take three flues perfectly similar in every respect, one 10, one 20, and the other 30 feet long, we shall find the first twice the strength of the second, and three times the strength of the third—and so on for any required extent, where the length does not exceed 20 diameters of the tube.

It will not be necessary to pursue this part of the subject further, except only to direct attention to the following tables, which have been constructed from the experiments bearing directly upon the elastic force of steam, internally as relates to tension, and externally as relates to the collapse of the flues:—

TABLE III.

Table showing the Bursting and Safe Working Pressure of Boilers, as deduced from Experiment, with a Strain of 34,000 lbs. on the Square Inch as the Ultimate Strength of Riveted Joints.

Diameters of boilers		Working pressure for ⅜-inch plates	Bursting pressure for ⅜-inch plates	Working pressure for ½-inch plates	Bursting pressure for ½-inch plates
ft.	in.	lbs.	lbs.	lbs.	lbs.
3	0	118	708¼	157¼	944¼
3	3	109	653¾	145¼	871¾
3	6	101	607	134¾	809½
3	9	94½	566½	125¾	755½
4	0	88½	531	118	708¼
4	3	83¼	500	111	666½
4	6	78¾	472	104¾	629½
4	9	74½	447¼	99¼	596¼
5	0	70¾	425	94¼	566½
5	3	67¼	404¾	89¾	539½
5	6	64¾	386¼	85¾	515
5	9	61½	369½	82	492¾
6	0	59	354	78¾	472
6	3	56½	340	75½	453¼
6	6	54¼	326¾	72½	435¾
6	9	52¼	314¾	69¾	419½
7	0	50½	303½	67¼	404½
7	3	48¾	293	65	396¾
7	6	47	283¼	62¾	377½
7	9	45½	274	60¾	365½
8	0	44	265¾	59	354
8	3	42¾	257½	57	343¼
8	6	41½	250	55½	333¼

Rule for ⅜-inch plates.—Divide 4250 by the diameter of the boiler in inches; the quotient is the working-pressure, being one-sixth the strength of the joints.

Rule for ½-inch plates.—Divide 5666·6 by the diameter of the boiler in inches, and the quotient will be the greatest pressure that the boiler should work at when new; that is, at one-sixth the actual strength of the punched iron.

The above table may be considered practically safe for the construction of boilers of good iron, to be worked at the pressure indicated in the second column; and the following Table of Equal Strengths of Cylindrical Flues may also be relied upon for a collapsing pressure of 450 lbs. per square inch:—

TABLE IV.

Table of Equal Strengths in the Cylindrical Flues of Boilers, from 1 to 4 feet in diameter, and from 10 to 30 feet in length, showing the requisite Thickness of Metal for a Collapsing Pressure of 450 lbs. per Square Inch.*

Diameter of flue in inches	Collapsing pressure of flue in pounds per square inch	Thickness of plates in parts of an inch		
		For a 10-feet flue	For a 20-feet flue	For a 30-feet flue
12	450	·291	·399	·480
18		·350	·480	·578
24		·399	·548	·659
30		·442	·607	·730
36		·480	·659	·794
42		·516	·707	·851
48		·548	·752	·905

* These calculations are founded on the supposition that the 20 and 30 feet long flues have no T-iron or angle-iron hoops. By the introduction of these necessary adjuncts at every 10 feet, or shorter distances, the plates for the 20-feet and 30-feet flues may be reduced to those of the 10-feet flue.

BOILER EXPLOSIONS.—At a very early period, or about the time when engineers and the owners of steam-engines found that a considerable amount of saving was effected by increasing the pressure and working the steam expansively (as had been done in Cornwall in the pumping-engine for some years previously), it was looked upon as impossible to apply the same principle of expansion to steam-engines which gave motion to a flywheel and the machinery of a manufactory. This imaginary impossibility existed for a considerable number of years; but time and experience revealed that the principle was applicable in both cases, and that the inertia or *vis viva* of a flywheel was the same as that produced by a vertical lift of the pump-rods and water combined in the reciprocating motion of the steam-engine. This having been ascertained, a new conception burst upon the less cautious

of the community, in the desire to do more work with less fuel and at less cost. Hence followed the desire not only to economise but to increase the pressure beyond the resisting powers of the boiler, and thus, through ignorance and without consideration, numbers of persons were induced to incur risks of explosions that too frequently were attended with loss of life. It was in this stage of disaster, when I was repeatedly called upon to investigate the causes of these accidents, that I became acquainted with the numerous defects of boiler-constructions, and the causes of explosions.

In these investigations I witnessed sufficient to convince me that the great majority of the accidents arose from the malconstruction of the boiler and excess of pressure, too frequently caused by ignorance or gross neglect. These facts led me to institute a long series of experiments, to determine the best and strongest form of boiler in the first instance, and the density, volume, and pressure of steam in the second. It moreover led to the establishment of an Association which, in my opinion, has saved more lives, and done more real service for the protection of property, than any other institution in the kingdom.*

It is true there are other associations on the principle of insurance, but these are established for the purpose of securing good dividends to the shareholders; whilst that over which I have the honour to preside is *perfectly gratuitous*, and is founded exclusively, at a comparatively small cost, for the protection of life and property. The Directors have no pecuniary advantage, directly or indirectly, and give their services gratuitously, for the benefit of those who choose to trust their boilers to *careful periodical inspection.*

I have considered it my duty to mention these facts, and to entreat the owners of this district to avail them-

* See page 9.

selves of the security offered by this association; and they will find not only greatly increased security, but a considerable amount of economy in the management and durability of their boilers.

Numerous theories have been promulgated to account for boiler explosions—such as shortness of water, red-hot plates, explosive spheroidal water, gases, collapse of flues, and over-pressure. The most reliable, however, are those of Mr. Colburn and the Astronomer Royal, both of whom appear to have arrived at conclusions nearly identical. Mr. D. K. Clarke has also directed his attention to this subject in his article on the Steam-engine, published in the last edition of the 'Encyclopædia Britannica.' Mr. Colburn, in a short but excellent treatise on the Causes of Boiler Explosions, disposes of the erroneous theories of electricity, decomposed steam, spheroidal ebullition; and at once advances the practical causes, instantaneous in their operation, which so frequently lead to boiler explosions. These, according to Mr. Colburn, are as follows:—

1st.—The rupture, under hardly, if any more than, the ordinary working-pressure, of a defective portion of the shell of the boiler—a portion not much, if at all, below the water-line.

2nd.—The escape of free steam from the steam-chamber, and the consequent removal of a considerable part of the pressure upon the water before its contained heat can overcome the inertia, and permit the disengagement of additional steam.

3rd.—The projection of steam combined, as it necessarily must be, with the water, with great velocity, and through a greater or less space, upon the upper sides of the shell of the boiler, which is thus forced completely open and broken to pieces.

4th.—The subsequent disengagement of a large quantity of steam from the heated water no longer confined within

the boiler, and the consequent projection of the already separated part of the boiler to a greater or less distance.

These appear to be the chief causes of boiler explosions, as announced by Mr. Colburn. The Astronomer Royal appears, in his paper read at the last meeting of the British Association in this town (Newcastle), to have arrived, with some slight variations, at similar conclusions.

The Astronomer Royal states that—'A little consideration of the changes in the state of the water and steam, which occur during the bursting of a steam-boiler, will show that very little of the destructive effect of an explosion is due to the steam which is contained in the steam-chamber at the moment of the explosion. The rupture of the boiler is effected by the expansive power common at the moment to the steam and water, both at a temperature higher than the boiling-point; but as soon as steam escapes, and thereby diminishes the compressive force upon the water, a new issue of steam takes place from the water, reducing its temperature. When this escapes, and further diminishes the compressive force, another issue of steam, of lower elastic force, from the water takes place, again reducing its temperature; and so on, till at length the temperature of the water is reduced to the atmospheric boiling-point, and the pressure of the steam (or rather the excess of steam-pressure over atmospheric pressure) is reduced to 0. It is the enormous quantity of steam, of gradually diminishing power, which is thus produced from water during the course of the explosion, that causes the disastrous effects of the explosion. Compared with this quantity, the small volume of gas which may happen to be in the steam-chamber at the time is, in boilers of ordinary construction, wholly insignificant, and may be entirely put out of sight in the succeeding investigation.

'2nd.—If we compare the course of changes in bursting

in two boilers—a large one and a small one, we see that the order of changes is the same in both; but that to reduce the temperature of a large body of water, by a certain number of degrees, a large volume of steam must escape; whereas to reduce the temperature of a small body of water, by the same number of degrees, it will suffice that a smaller volume of steam (smaller in the same proportion as the bulk of water) escapes. Thus it will appear that the whole volume of escaping steam at a given pressure, and the whole destructive energy of the steam, are proportional to the bulk of water.

'3rd.—For measure of the destructive energy of the steam, we must suppose the simplest and most easily measurable case—namely, that the steam in expanding drives the piston along a uniform cylinder. It is necessary to ascertain the value of the pressure (F), when the steam has expanded so far as to have pushed the piston to the distance x. Then the measure of the total energy is $\int d\,x\,F$, the integral being taken from the point where the piston was in contact with the water to the point where the excess of pressure of the steam above atmospheric pressure $= 0$.'

From my own inquiries in the more early stages of boiler-explosion, I have generally traced these catastrophes to *over-pressure*. This term *over-pressure* has been objected to, but the literal meaning of the expression is, that whenever the elastic force of the steam from within exceeds that of the resisting powers of the boiler from without, explosion ensues. This may arise from such causes as defective safety-valves, or corrosion, where explosion may take place at the ordinary working-pressure; or it may arise from collapse of the flues, or from malconstruction. One thing is however self-evident, viz., that the strength of the boiler in all its parts must greatly exceed that of the pressure of the steam if we would avoid explosions.

Hitherto we have confined our attention to boilers constructed of rolled plate iron, under the assumed impression that this is the only material calculated to make a good boiler. At the present moment this is apparently the case, but the time is probably not far distant when we may save one-third of the weight without incurring any diminution of strength. If we look around us, there are evidences in every direction of changes and improvements, tending to a revolution in the chemical as well as the mechanical properties of iron. We know to a fraction the exact quantity of carbon, or any other element or chemical compound, that must be left in or taken out in the fusing and manipulating process of making iron or steel; and we can measure to a nicety the percentage of carbon that is necessary to produce what is called homogeneous iron, or that description of metal that partakes in a greater or less degree of the characteristics of both iron and steel. These combinations are highly valuable, as they can be modified to any extent, and thus give to the operator all the requirements for producing iron of a ductile, fibrous, or crystalline structure. Now, although these diversified combinations and powers of varied production are in operation at the present time, we have not yet attained that degree of certainty in the manufacture, as to produce either iron or steel of the exact quality and description that is required. There still exists a want of uniformity of structure, and until that is accomplished, we must be content to take for the purposes of calculation the minimum instead of the maximum powers of its resistance to strain. I do not, however, despair of realising this desideratum in the manufacture, as the number of distinguished men who are now seeking to attain that object is a sufficient guarantee for its ultimate success.

United to chemical combinations and analysis in the manufacture of iron, is a due observance of the varied

forms and conditions of the processes in the mechanical manipulation to which the blooms or ingots are subjected. These, when carefully conducted, having regard to temperature, will produce the requisite elongation of fibres, and that amount of ductility or hardness which may be required as a property of a given description of iron or steel, and that probably without injury to that homogeneous character so much wanted in constructive art. It is quite evident that the old process of piling and welding a number of bars together to make a plate, or any other particular form, is not a sound process of manufacture, as the welding is often imperfect, and hence follows that laminated appearance of the fibrous and crystalline character invariably present in plates and large masses made from piled bars. This is not, however, the case, when the article is made from the homogeneous ingot, which, having been cast, is then subjected to consolidation by the hammer and the rolls; and thus, by repeated heating, its crystalline character is partially reduced to the fibrous state by impact, elongation, and compression, and by these devices its resistance to strain is augmented and greatly improved. With this prospect before us we may, therefore, look forward with hope to a more perfect state of manufacture, and the realisation of that desideratum which is still wanting—namely, perfect uniformity in the strength and other properties of both iron and steel. It is true we have had boilers made and ships built from steel plates, but we are still wanting in that degree of uniformity of character in the manufacture as would indicate with certainty that the whole batch was equally strong, as a single faulty plate might prove equally fatal to the structure as if the whole were of that stamp.

We have now treated of the boiler; but there is another circumstance of great importance in the construction of

steam-engines, particularly those adapted to the drainage of mines, that must not be overlooked. The lamentable and disastrous occurrence which took place at Hartley Colliery, by the breaking of a cast-iron engine-beam a few years since, must be fresh in the recollection of the public and those now present. This unfortunate catastrophe, by which upwards of two hundred valuable lives were lost, was chiefly due to the uncertainty of cast iron when cast in large masses; subject, as is generally the case, to unequal contraction in the process of cooling. Altogether cast iron is never a perfectly secure material when subjected to severe strains or the force of impact; it is nevertheless of great value in most constructions. On almost every occasion, where the casting is large, there is a degree of uncertainty, arising from the want of proportion of the parts, secret flaws, want of attention to uniformity in the process of cooling, and the danger of having some parts of the casting in a state of unequal tension—technically called *hide-bound*—which ultimately leads to fracture. The greatest possible care is therefore necessary in every description of beam or girder, to select, in the first instance, the proper mixture of metal; to study the art of proportion, in order to attain perfect uniformity in the cooling, and to relieve the article—whatever it may be—from unequal strain in the contraction of its parts. This is an art surrounded with many difficulties, as every casting calculated to sustain severe strains is subject to unequal contraction, unless it is carefully prepared and duly proportioned to admit of uniform tension in the combination of its parts.

I have been the more particular on these points, as I have witnessed, in my own experience, so many failures arising from want of knowledge, or neglect of these important considerations, that I have ventured to direct your attention to them, and to show how essential it is to

security and ultimate success in the production of sound castings, to watch carefully the laws of crystallization, by which Nature works in the process of passing from the fluid to the solid state.

On the question of engine-beams we are, however, relieved from all doubts on the score of security, by the employment of wrought instead of cast iron. It has often occurred to me, in the exercise of my profession, that in engine-beams, as in bridges, a judicious combination of that material would relieve us from all anxiety as regards safety; and, moreover, it would establish a new and important era in the application of wrought iron in place of cast iron for the main beams of engines.

This idea is not new, as it occurred to Mr. Murray, of Chester-le-street, and Mr. John Taylor as well as myself; and the firm at Manchester has constructed for these gentlemen three large beams of this class. The first was at work shortly before the Hartley catastrophe; and having been constructed under my own immediate superintendence, I have considered that a description of its strengths and other properties may not be unacceptable to the miners of this and other districts.

The beam, of which the annexed plate is an engraving, is of the tubular form, composed entirely of plate iron, with cast-iron centre sockets to receive the axis, and crosshead of the pump-rods, and parallel motion.

The dimensions of the beam are as follows:—Length, 28 feet 8 inches; depth, 5 feet 6 inches; and width, 2 feet. The sides are of $\frac{3}{8}$ths iron, supported between the flanges with T-iron over the joints, and corresponding strips outside. The upper and lower flanges are composed of the best double-worked plates and covering plates, chain-riveted, each 2 feet wide and $\frac{3}{4}$ths of an inch thick; and these are riveted to the sides by double-angle irons, as shown at *a*, *a*, *a*, *a*, &c. For the reception of the main

WROUGHT IRON ENGINE BEAM.

FIG II.
Elevation.

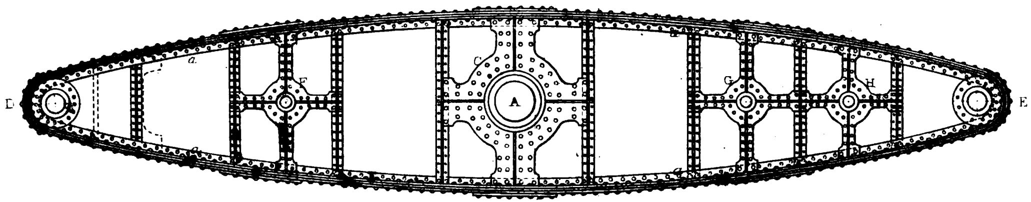


FIG III.
Plan.

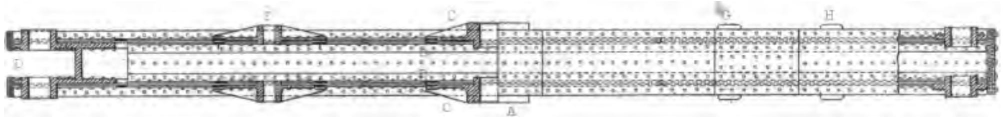
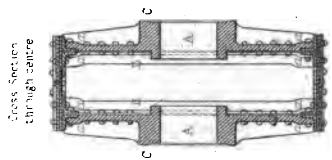


FIG IV.



E. Jacob del.

H. Adlard sc.

Scale ¾ inch. 1 Foot.

London. Longmans & Co.

centre at A, are two cast-iron plates firmly riveted to the sides and angle-irons of the flanges, as also to two T-iron ribs inside, which stiffen the side at B, B. At the extreme ends, D, and E, and at F, G and H are similar castings, to receive the pump-rods, parallel motion, air-pump rods, &c. These constitute the more important features of the structure, as may be seen from the drawings.

The calculation of its strength, according to the formula $W = \frac{a\,d\,c}{l}$, is as follows:—

Let l = the length of the beam . . . = 28 ft. 8 in.
„ d = the depth „ . . . . . = 5 ft. 6 in.
„ a = the area of the bottom flange = 56 sq. in.; and
„ c a constant derived from experiment . . . . = 80.

Hence $W = \frac{56 \cdot 67 \times 5 \cdot 5 \times 80}{28 \cdot 66}$ = 870 tons as the breaking weight of the beam in the middle.

Now, as the beam, in its reciprocating action, is subjected to alternate strains of tension and compression, and as the load to be lifted will never exceed from 85 to 90 tons, we may safely consider the ratio of strength as 870 : 90, or nearly as 10 : 1—a safe margin of strength; and this will amply provide for the force of impact to which every description of engine-beam is subjected in case of any accident to the buckets or pump-rods in the pit. Besides there is this additional security, that wrought iron is three times the tensile strength of cast iron; and, being a fibrous and ductile material, there is less chance of it snapping asunder without notice, and subjecting the helpless miners, as in the case of the Hartley pit, to an irremediable and lingering death. With these facts before us, and the means of rendering our engines free from danger, I have to urge upon the coalowners and engineers of this and other districts, and in cases where there are

doubts of security, and so in all future engines, that the main beams be made of wrought iron.

Having thus pointed out what is necessary to be observed in the application of iron to the steam-engine (I speak of it in its general sense, without entering into the classification of iron and steel to the principal parts of the steam-engine), I may, in conclusion of this division of the subject, notice the cylinder, connecting rod, and crank, as requiring careful attention on the part of the constructor and engineer. The forces applied to the cylinder, which is always made of sound cast iron, are upon its circumference, bottom, and cover, the same as those applied to the boiler; and the same formula may be used in the calculation in regard to strength, but with this difference, that seven tons per square inch must be taken as the ultimate tensile strength of the material. The same may be said of the connecting rod and crank, excepting only as regards the transverse section of the former, which should be, in the middle (if made in the form of ribs or webs) three times the diameter of the solid part of the rod at the beam and crank.

As respects the crank, the same formula—

$$W = \frac{a\,d\,c}{l}$$

used for calculating the strength of beams, may be applied, with this difference only—that the constant c, for wrought iron, is 80, whilst that for cast iron is only 26. For ordinary purposes these calculations will be found practically safe, but, in all these constructions, I must confess that much depends upon the experience and practical knowledge of the engineer, and that a keen eye to proportion and a sound judgment are frequently of much greater value than a whole volume of algebraical formulæ.*

* Our general method of computation is as follows:—

I much fear that in these investigations I have enlarged to an extent sufficient to try your patience; but as steam, the steam-engine, and the material of which the latter is composed, enter largely, in these days of iron, into our daily occupations, I trust I may be excused if I have been a little prolix, and trenched to some extent upon your valuable time. I must now, however, direct your attention to another part of our subject, namely—

THE APPLICATION OF IRON TO MILLWORK.—The trade of the millwright is of long standing. He was the great pioneer of mechanical progress, and for many centuries exercised the functions of engineer, wheelwright, and occasionally that of blacksmith, fitter, and turner. In fact, until of late years, the millwright of former days monopolised nearly the whole mechanical industry of the

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Diameter of piston rod = from $\frac{1}{8}$ to $\frac{1}{10}$ area of cylinder or

Where d = diameter of piston rod and P = the pressure of steam in the cylinder in lbs. per square inch.

$$d = \sqrt{\frac{P}{2267}} + \cdot 2 \text{ for wrought iron.}$$

$$d = \sqrt{\frac{P}{3396}} + \cdot 19 \text{ for cast iron.}$$

Main centre, $1\frac{1}{2}$ to 3 times diameter of piston rod.

For the crank—

Where D = diameter of crank shaft,
d = diameter of crank pin,
HP = the indicated horse-power of engine,
R = the number of revolutions of flywheel per minute,

$$D = \sqrt[3]{\frac{250HP}{R}}$$

and if S = the pressure per square inch of the steam in the cylinder,

$$d = \sqrt{\frac{S}{200\pi}}$$

Depth of eye . . .	= 0·9D
Diameter of large end .	= 1·8D to 2 D
Web	= 0·55D

Connecting rod—wrought iron—

Diameter of neck = $1\frac{1}{4}$ times diameter of piston rod,
Swelling, $\frac{3}{8}$ inch per foot of length.

country; and such were his jealousies of the rights and immunities of his profession, that he held in comparative contempt all other trades that could not assign reasons for the exercise of those pursuits which he erroneously claimed as his own peculiar privilege. These exclusive notions were, however, the errors of the age in which he lived; they were not confined to the millwright, but extended, under a very limited scale of industry, to almost every other trade and profession. The invention of the steam-engine, and the introduction of improvements in the manufacture of iron, led to changes, and established a new era in the industrial resources of the country, and to a great extent demolished the prescriptive rights and privileges of the millwright and other similar trades.

These discoveries, and the extended use of iron, opened up new fields of enterprise and wealth: it is, however, but fair to the millwright to state that he was amongst the first who availed himself of the changes by which he was surrounded, and from the days of Smeaton up to the present time, the millwright has been, to a great extent, a worker in iron. Smeaton employed iron in his construction of the Carron Boring Mills, and the late Mr. Rennie took advantage of the improvements in progress at the close of the last century, and constructed the whole of his wheels and shafts of cast iron. Since then, still greater improvements have been effected, in substituting wrought iron for shafts instead of cast iron. Waterwheels, turbines, and almost every description of mill-machinery are now made of cast and wrought iron; and the advance made in this department, by the introduction of light shafts at high velocities, is probably as great as in any other branch of mechanical industry.*

THE APPLICATION OF IRON TO MACHINERY may be

* *Vide* 'Mills and Millwork,' &c. Longmans and Co.

classed amongst those improvements which have followed so rapidly one upon another for the last half-century. The inventions of Arkwright, Crompton, and others could not have been executed but for the application of iron; and it is fortunate for the resources of the country, that its extended manufacture has kept pace with our industrial progress. I am not able to state the amount of consumption of iron in machine-making alone, but taking that for cotton-machinery in only one of our largest firms, that of Messrs. Platt and Co. of Oldham, I should average at 400 to 500 tons per week; and in that of my late brother, Sir Peter Fairbairn, of Leeds, in flax and other machines, at 250 to 300 tons per week. If we consider the consumption which is in daily progress amongst the numerous machine-makers for the manufacture of the textile fabrics, and reflect that from two-thirds to three-fourths of the value of cotton and flax machinery is labour; we may form some estimate of the number of persons employed in this important branch of industry, and also of the comparative comforts they enjoy in their social condition and the domestic economy of their households.

In the manufacture of machines for spinning and weaving, and the manufacture of tools—another ingenious and important branch of industry—we may safely conclude that we are chiefly indebted for the development of our iron resources to these particular trades, arising from the exactitude, beauty, and precision of the automaton machines in daily operation before us. Any person inclined to study the movements, precision, and certainty of action which pervade the working of the blowing, carding, combing, drawing, roving, spinning, and weaving machines, must be struck with the beauty of their construction—I was going to observe the intelligence with which they perform their respective operations, and that too without assistance from the hands of the attendant, whose duty is

simply to supply the material and remove the successive deliveries of the finished article as it comes from the machine. During the International Exhibition of 1862, there were few of us but observed with delight the movements of the machinery for spinning, weaving, and finishing cloth; the machine for making cards; the combing and the spool machines, for winding thread on bobbins, and tying the ends to the wooden ring when the exact length of thread was wound on. All these operations must have struck both the initiated and the uninitiated with wonder, and it is no mean praise when we state that a considerable number of these machines have been invented and perfected in this country.

In addition to these, I may refer with some degree of pride to our tool-making; and here I may go back to the city of my adoption, and we shall find Manchester among the first, if not the very first great centre of mechanical progress. Most of the machines I have enumerated have had their origin in that town and the surrounding district, and it is not too much to say that our self-acting tools date from the same quarter, and that we are still fruitful of resources for original contrivances and extended improvements in mechanical science. These are some of the results of applied science and the use of iron; and I entertain hopes, when the time arrives for our kinsmen on the other side of the Atlantic to return from the arts of war to those of peace, that we shall have a new reign of progress, and a still more extended development of practical science applied to the industrial resources of the world.*

Before closing these remarks, allow me briefly to direct your attention to some other changes and improvements that have taken place, and in which your own townsman,

* These remarks were penned before the termination of the struggle between the Federal and Confederate States of North America.

Sir William Armstrong, has taken a prominent and an active part—namely, the improvements in gunnery, for the destruction of iron-plated ships and forts. There cannot exist a doubt as to the results of these improvements, and the great changes that have been effected and are still in progress, as to the size of the gun and the weight of metal that can be projected against either a ship or a fort. It was only the other day that I was present at the trial of the largest gun ever manufactured in this or perhaps any other country. That gun was made at the Elswick Works. It weighed 22 tons, and projected, with a charge of 70 lbs. of powder, a 600 lb. shot, at an initial velocity of 1,260 feet per second. Now a missile of this immense weight, and at that high velocity, would smash-in the sides of any ship ever yet constructed with a crash that would almost send her to the bottom; and it becomes a question with myself and my colleagues of the Iron Plate Committee (*antagonistic to the guns*), how we are to get over the difficulty. It is clear that plates of eight or nine inches thick would not resist such a projectile, and we have therefore to consider what other means should be adopted to keep so unwelcome a visitor outside of either forts or ships; or whether it would not be better to give it a free passage right through, save the expense of the armour-plates, and transfer the cost of these constructions into steam-power as the means of escape. In my opinion the power of attack and retreat are equally valuable in maritime warfare; and as speed is an important element in ships of war, it is a consideration of some importance to determine whether the manœuvres of the ship or the large guns are to claim the victory—both of them essential in naval constructions. To manœuvre with celerity must be looked upon as an equivalent for heavy ordnance; and as no vessel can carry iron plates of sufficient thickness to resist such monster guns, the next best thing to

do is to make them light and active, with abundance of steam-power, to outmanœuvre the enemy.

It has been a subject of doubt whether guns of such immense calibre can be made of sufficient strength to render them safe, and whether they could be worked on board ship. In reply to that question, I have to state, from what I have witnessed on the trials at Shoeburyness, that both may be accomplished, and that important results may be obtained by the introduction of a new build of vessel to support and work with safety 600-pounder guns.

In offering these remarks, I have probably trenched upon your patience. Allow me, however, in conclusion, to inform you that we have not yet extracted the whole of the mineral resources with which this highly-favoured country abounds. There are still left large supplies of both coal and iron, although we have no reason to suppose that they are inexhaustible. On the contrary, we are bound by every principle of duty to be economical in their use, not only in the reduction of the ores, but also in the manufacture of iron and its appliance to constructive art.

I

ON THE COMPARATIVE MERITS OF THE MACHINERY OF THE PARIS UNIVERSAL EXHIBITION, 1855.*

In this extensive collection of mechanical constructions, I have endeavoured to classify and bring together such a series of facts in connection with the various forms and adaptations of the objects that have come before me, as I trust may prove advantageous in extending the industrial pursuits in which this country is so largely engaged. In the arrangement that was adopted, the Jurors might probably be expected to confine their observations to the articles specified in their respective classes; but conceiving that a more general and comprehensive description of the mechanical contrivances displayed in this exhibition might be useful, I have endeavoured to record them in such form as to show in what we are deficient, and wherein consists our superiority over other countries. The Paris Universal Exhibition differed from all others in the extent of its productions, the variety of its objects, and the facilities afforded for the disposal of the exhibited articles at a fair market-price; these conditions were of great value to the exhibitors, in the immense selection submitted to view. In this respect it differed from the Great Exhibition of 1851; and looking at the numerous specimens of raw material and the display of manufactured articles, we at once

* Extracted from Mr. Fairbairn's report, addressed to the Right Hon. Lord Stanley of Alderley, President of the Board of Trade.

conclude that it was an immense bazaar, from which might be selected every description of manufacture and almost every kind of produce. In this Exhibition nothing surprised the observer more forcibly than the beauty and the extent of the articles offered for inspection, and the great skill by which such vast and varied forms of manufacture were produced. In the department of Machinery, it may be interesting to trace the development of many ingenious contrivances. The self-acting and almost creative power of machine tools, and the facilities with which that branch of manufacture is endowed for the production and reproduction of other machines, is a feature of incalculable importance to the national industry. Many of those now in constant use had no existence a very few years since; but such has been the progress in mechanical science, that the finish of work performed by many of these machines surpasses the most skilful efforts of the human hand.

Such, in fact, are the advantages derived from the introduction of this kind of machinery, that the produce of our manufactures is multiplied and extended tenfold, and in many cases upwards of a hundredfold. In the process of copying, or the reproduction of the same article by mechanical means, there were in this exhibition numerous contrivances, for which we are indebted to the Americans, and their system for the formation of objects by *dummies*, or what may be called the 'pantagraph' system, by which the form of every part of the object is traced, and by proper tools and cutters a facsimile of the article to be copied is produced. This system of reproduction is fast coming into general use, and many examples of its utility were shown at the Paris Exhibition.

STEAM-ENGINES AND STEAM MACHINERY.

The number of Steam-engines in the Exhibition was 112, consisting of 71 stationary, 24 marine, and 17 loco-

motive. The following countries were represented by these as follow :—

Name of country	Stationary engines	Locomotive engines	Marine engines
France	25	6	11
Great Britain	11	2	11
Austria	11	1	—
Prussia	1	1	—
Belgium	1	3	—
Hanover	—	1	—
Wurtemburg	—	2	—
Baden	—	1	—
Sweden	11	—	1
United States	11	—	—
Holland	—	—	1
Totals	71	17	24

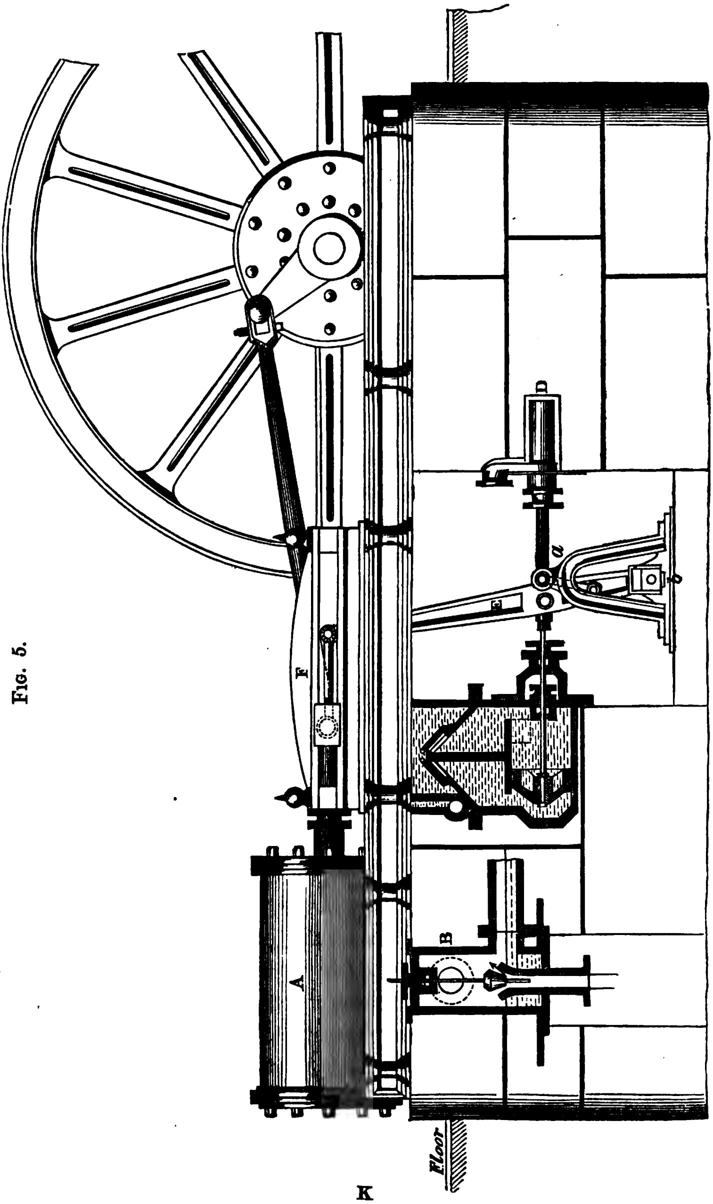
STATIONARY ENGINES.

The department of Stationary Engines comprised almost all the varieties of construction—horizontal, vertical, and oblique. The horizontal with one cylinder appears to be much in demand, and the vertical with two cylinders (upon Woolf's principle), having an expansion from four to five times the volume of the small cylinder, has been for the last half-century in general use in France, and almost equally so in Belgium and most other parts of the Continent. They are worked generally at a pressure of 40 lbs. to 50 lbs. on the square inch, and the steam is supplied from boilers with the fire under two longitudinal tubes or generators. These tubes are connected with the boiler at both ends, and the heated currents, having made two or more circuits of the boiler, make their escape to the chimney in the usual way. These boilers are not, in my opinion, superior in the economy of fuel to those with internal flues, or to the tubular system as constructed in this country; but their power of resistance to internal pressure is greater than in boilers of the English construction. The single-cylinder horizontal appears to be gaining ground

upon the double-cylinder vertical engine, and doubtless this arises from their reduced cost and simplicity of construction. Their compact form and the limited space which they occupy are considerations of some importance, and now that metallic pistons are so accurately constructed, the wear-and-tear upon the cylinder is greatly reduced. The condenser in this construction is placed below the cylinder, and the air-pump is worked by a lever attached to the crosshead of the connecting rod and horizontal slides. The air-pump, like the cylinder, is placed horizontally, and various forms and devices are adopted in order to give the required motion to the feed-pump, and other organic parts of the engine. As an example, the annexed engraving will convey a pretty accurate idea of the arrangement generally adopted in this description of engine, and the methods employed for working the air-pump and feed-pump. In this construction, fig. 5, A is the cylinder, B the condenser, C the air-pump, worked with a solid piston, and D the feed-pump. The lever E receives motion from the links attached to the crosshead and slide at F; and in order to produce a perfectly horizontal motion in the connecting rods of the air-pump and feed-pump, the oscillating lever E is suspended by two more links at *a*, which leave it free to slide up and down at the foot *b*, and thus a horizontal movement is effected in the two pump-rods before mentioned.

The valves in most of those engines are of the usual construction, worked by an eccentric from the flywheel shaft; but they have the peculiar feature of a variable lap working through the spindles of the valves, and by a moveable cam, which works in a square frame at the end of the spindle, any required amount of expansion may be obtained. This appears to be a very ingenious and a simple contrivance, and seems to answer the purposes of cutting-off the steam at any re-

FIG. 5.



HORIZONTAL CONDENSING ENGINE.

quired point of the stroke. The consumption of coal in this engine is represented to be 1·36 kilogrammes of coal per horse-power per hour, or about 3 lbs. English; and in order to convince the public of the truth of this statement, the makers publicly offer a guarantee that it shall not exceed that amount. The application of the horizontal in place of the vertical cylinders is an idea nearly as old as the steam-engine itself; but the difficulties formerly were the want of tools and other conveniences for attaining accuracy of construction, in order to render the working parts smooth and steam-tight. This is no longer an obstacle, as the perfection of the automaton tools surmounts all those inconveniences; and hence the conceptions of former days, which, for want of instruments requisite for construction, have remained *in statu quo* up to the present time, are at length accomplished. Such are the retardations and such the advancements of science, one generation conceiving schemes and projects which, for want of the means, they are unable to execute; and the next, having in process of time realised those means, are enabled to perform what their predecessors had tried in vain to accomplish. In the realisation of old ideas, there is generally a strong desire on the part of the successful practitioner to force upon the world his adopted bantling as an original conception, forgetting at the same time what he owes to his predecessor who first made the discovery. No doubt there is great merit in being the first to perfect an original invention, but there is no merit in claiming as a discovery what was known before; and this desire for originality of conception is as strong, if not stronger, in the minds of our French neighbours than among ourselves. There is great credit in being the first to render useful what was before considered impracticable, and he who accomplishes this is certainly entitled to acknowledgment. In the Paris Exhibition the claimants for originality of

design, and the practical application of schemes previously known, were numerous; and although the desire to become an original inventor may, in some cases, be objectionable, it nevertheless has its advantages, in stimulating that active race to renewed exertions in furtherance of future developments in practical science.

The horizontal engine, on account of its reduced cost and compact form, is likely in small engines to supplant the old vertical arrangement; and assuming the same rate of expansion to be employed, and the steam to be cut off at one-fourth or one-fifth of the stroke, the result, so far as regards the economy of fuel, will be the same as that derived from the double cylinder. In this country these improvements, although well known, are not carried to the same extent as in France; and although the same kind of engine is in operation, we have made slower progress, excepting in the horizontal non-condensing engines, which in Lancashire have got the name of *Thrutchers*, and are now extensively used as an auxiliary power to the condensing engine in most of the manufacturing districts. There is, however, still wanting a well-digested arrangement of the horizontal condensing engine, compact in form, and correctly adapted to the work it has to perform: the Paris Exhibition presented in this respect numerous examples for our guidance.

LOCOMOTIVE ENGINES.

The locomotive engine had its origin in this country, and those of English construction still retain their superiority over all others, both in design and construction.

It would, however, be unjust not to accord great merit to the many excellent specimens contributed to the Paris Exhibition by Continental manufacturers. Nearly all of them were somewhat complex in arrangement and design,

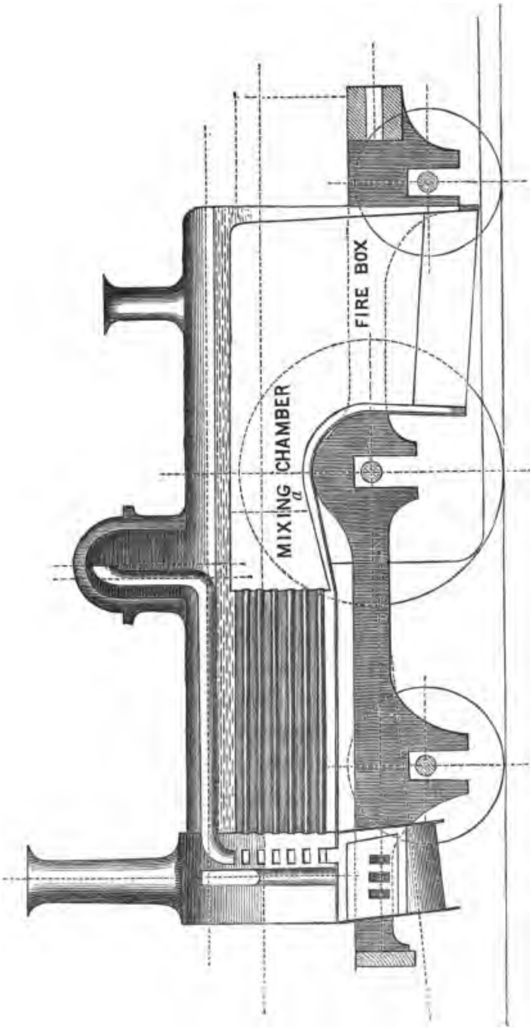
but evince great care and attention to solidity of construction. Many of the engines were upon the system of Crampton, with the valve-motions outside, which gives to the engine an appearance of complication that does not occur in those of English construction. In other respects the engines are nearly the same as our own, with the link-motions and other indispensable attachments.

There was, however, one engine to which I would refer —'The Eugénie,' Fig. 6, built on Mr. M'Connell's principle of the large firebox and short tubes. This and another from Messrs. Stephenson & Co., of Newcastle-on-Tyne, were the only English locomotives exhibited; and, considering the large number brought forward by our Continental competitors, the English constructions were very imperfectly represented. Mr. M'Connell's engine is on the same principle as the large goods and express engines now working on the London and North-Western Railway. They have several valuable properties, which it may be useful to enumerate in connection with the experimental trial made with the 'Eugénie' on the London and North-Western Railway, the results of which are as follow:—

Results obtained during Three Weeks' Running on the London and North-Western Railway, on a course of 83 miles with Express Trains.

Remarks	No. 1 Trial	No. 2 Trial	No. 3 Trial
Number of carriages	15	12	9
Total weight	75 tons	60 tons	—
Coke burnt, per mile . . .	19 lbs.	15 lbs.	—
Speed per hour	40 miles	45 miles	75 miles
Ratio of evaporation of water to coke	8·9 : 1	8·75 : 1	—

Fig. 6.



LONGITUDINAL SECTION OF THE EUGÉNIE.

Scale $\frac{1}{64}$

The principal dimensions and particulars of this engine are as follow:—

Diameter of cylinder .	15 in.	Diameter of boiler .	4 feet
Stroke of piston . .	22 in.	Length of barrel of do. .	10 ft. 6 in.
Diameter of driving-wheel	7 ft.	Length of firebox . .	3 ft. 9½ in.
Heating surface, firebox, &c.	159 sq. ft.	Number of tubes . .	414
Tubes	731 sq. ft.	Length of tubes . .	6 feet
Weight of engine in working condition	21 tons 18 cwt.	Outside diameter of tubes	1¼ in.

In these experiments the engine ran with perfect steadiness in all its parts, and made a journey of 55 miles without stopping for water.

This engine burns coal of the worst quality almost entirely without smoke, and with great economy; the generation of steam is most powerful and regular, both at high and low speeds. The arrangement of the furnace and large mixing-chamber effects the combination of the gases, so that there is little or no smoke, and permits the use of a much larger number of smaller tubes, which afford a tube-surface of the same extent as in the ordinary arrangement, but of much greater efficacy. The curve or recess employed in the cylindrical part of the boiler, shown at *a* fig. 6, is of great advantage, as it forms a metallic bridge between the firebox and mixing-chamber, where the gases combine, and where it is easy to admit hot or cold air, in sufficient quantity to complete the combustion, as the heated gases are disengaged from the fuel. This hollow curve adds also to the steadiness of the engine as the whole mass of the engine is brought nearer the rails, thereby lowering the centre of gravity, and producing about the same advantages as that obtained by the use of outside cylinders.

It would be invidious to draw inferences, or to make comparisons on the construction of machines that are so nearly similar in character and almost identical in prin-

ciple. The locomotive engine is the same in all countries, and, however varied in form or construction, it invariably consists essentially of the blast-pipe, tubular boiler, and outside or inside cylinders.

Some slight additions and improvements have been effected in the different motions and organic parts of the engine, but they all resolve themselves into enlarged heating surfaces in the boilers, and the employment of the exhaust tube; which is, in fact, the bellows that blows the fire, and maintains the supply of steam under every circumstance and velocity at which the engine may travel. In constructions of this kind the following conditions must be observed—namely, the proportions of the furnace, tubular surface, and the blast-pipe; and these once accomplished, the mere form of construction becomes a consideration of less importance.

Doubtless much has been done in proportioning the working parts—such as the wheels and axles, motions, connecting-rods, &c.—to the work they have to perform; and nothing more is apparently left to be accomplished, unless it be to increase the pressure, and by an extended expansion to effect greater economy in the consumption of fuel. The foreign engines exhibited in the annexe were substantially made, and some of them too much so; as a considerable amount of weight and expense might have been saved in the reduction of the material where it is not wanted, and where it does not add to the strength of the engine. In the foreign engines there appeared to be a want of accurate proportion in the distribution of the material, and of simplicity in the movements; and having had some experience in the construction and proportion of the parts, I am probably the better able to judge of their comparative merits. Under all the circumstances, I am, however, of opinion that the locomotive engines of Great Britain are superior to most others: and although they

may not have the same amount of polish, there is, nevertheless, a simplicity of form and a soundness of workmanship which give character and stability to these important constructions.

MARINE ENGINES.

In this department there was little to recommend, as the contributions were very scanty, and will not bear a comparison with those that were exhibited at the Great Exhibition of 1851.

With the exception of a pair of neat engines from the Mortala Works in Sweden, two pairs from Cail & Co., and a small pair from Tod and M'Gregor, of Glasgow, constructed for the screw-propeller, there was nothing excepting some small models that deserve the name of marine constructions. The rest were not of the best or simplest forms, and cannot, therefore, be considered of much value, either as regards design or construction.

It is to be regretted that, owing to the exigencies of the war, and the great demand for marine engines, the English makers were unable to forward any for exhibition. In 1851 the Crystal Palace was supplied with some splendid specimens of marine construction, and we have only to enumerate the names of Boulton and Watt, Penn, Napier, Maudslay and Field, and others, to call to mind the superior designs and construction for which the British engineer is so justly famed.

It will be fresh in the recollection of all those conversant with the steam-engine, that considerable advances have been made of late years in the use of steam worked expansively and at high-pressure. This has been strikingly exemplified in every description of engine, and it is evident that, both in land and marine constructions, the tendency is to use steam of greatly increased pressure.

That increased pressure, when accompanied by a more extended expansion, is invaluable as an element of economy in the consumption of coal; and under certain conditions the greater the length of stroke through which the steam is worked expansively, the greater the benefits to be derived from its application. I have no doubt that the experiments of Regnault on steam, and those of Joule on heat, will ultimately lead to a new and more extended application of this principle.

All that is wanted in this new application, will be the construction of boilers of sufficient tenacity to resist from four to six times the pressure at which it may be prudent to work the steam; and with these precautions, I see no reason why we might not reduce the weight of our engines, and increase the pressure of our steam up to 100 lbs. or 150 lbs. on the square inch.*

HYDRAULIC ENGINES AND MACHINES.

The turbine appears to have almost entirely supplanted the waterwheel in the estimation of the French engineers and manufacturers; and the millwrights, availing themselves of the benefits conferred by the Universal Exhibition, have contributed a great variety of articles of this kind. In many parts of France, Switzerland, and Germany, particularly in the mountainous districts, where fuel is expensive, the turbine is of great value; and in many parts of the country, where water and high falls abound, it is a more convenient and less expensive machine than the waterwheel. On the subject of turbines and their comparative economy, there exists, however, considerable difference of opinion; the advocates for the turbine contending that it is as effective as the waterwheel, and

* Since the above was written, this has been accomplished.

yields from 70 to 80 per cent. of the theoretical work of the fall—others, again, asserting the superiority and economy of the waterwheel. In my own experience, I have found the work done by turbines to range from 50 to 60 per cent. of the work due to the fall, and in some cases as high as 65 to 70 per cent.; but they are certainly not so effective as breast-wheels, which, when well constructed, yield from 75 to 80 per cent.; in turbines there is, however, a considerable reduction in the first-cost of the machines, and, looking at their great velocity when propelled by high falls, and their relative weights, they are certainly preferable to waterwheels, under certain conditions and in some localities. In other respects, where the fall of water does not exceed fifty feet, the waterwheel will be found to possess, as far as my experience goes, considerable advantages over the turbine.*

The hydraulic machines of this country have been almost exclusively confined to the waterwheel, and the hydraulic engine for raising water from mines. This latter engine is worked by a head of water, which from its initial force raises a piston or plunger in a cylinder; and by opening a valve, when the length of the stroke is attained, allows the water to escape, and the weight of the mass raised reacts upon the plungers in the pit, and raises the water in the usual way by the plunger-pump. This is a very simple machine, which may be applied for the purpose of raising water in mountainous districts where high waterfalls exist.

The waterwheel has maintained its ground from time immemorial against every new invention, and all competition; and I am persuaded that, for simplicity of form,

* Since this was written, I have had reason to modify this opinion, as considerable improvements have been effected in the construction of the turbine, which has raised it on the score of efficiency to nearly that of the waterwheel.

durability of construction, and economy of action, it still retains its claim to importance. It has received many improvements—first from the experiments of Smeaton, the constructions of Rennie and Hewes, and, still more recently, from myself. The experiments of Smeaton first determined its relative powers when employed on high and low falls; the late Mr. Rennie improved its construction, and the mode of applying the water; and Mr. T. C. Hewes, of Manchester, was the first to apply and perfect the flexible malleable iron radius rods to the shrouds or periphery in place of arms.

All these inventions, including my own, for ventilating the buckets and working-wheels to great depths in back-water, have contributed to make the waterwheel one of the most economical and perfect machines extant.

The researches of Poncelet showed the best form and curvature for the buckets; and it would be ungracious to deny that the turbine itself would never have existed, in its present state of perfection, but for the sound principles first promulgated by that distinguished philosopher, in his lectures on Hydraulics and Hydrostatics. Altogether, these machines were well represented in the Exhibition; and although they are comparatively useless in Great Britain, where the steam-engine is so extensively employed, yet on the continents of Europe and America, where water is plentiful, they are of great and paramount importance, as a motive power in the progress of the industrial arts.

MACHINERY FOR THE MANUFACTURE OF COTTON, SILK, FLAX, AND WOOL.

It would ill become me to attempt any description of machines used in the manufacture of the textile fabrics, when it is known that the much abler pen of Professor

Willis, of Cambridge, has undertaken that duty: suffice it to observe, that in the French, Belgian, and Zollverein departments of this description of machinery, several excellent specimens were to be found. Some of them were highly finished; and the new combing-machine, made by Messrs. Schlumberger & Co., appeared conspicuous in the Paris Universal Exhibition for its ingenuity, and the efficiency of its operations. This machine has been greatly improved by Messrs. Hetherington and others, since its first introduction into Manchester and Bradford; and in the preparation of cotton for fine yarns, it is one of the most valuable machines that has come into use for many years. In the combing of flax and wool it is becoming equally important, and its application to the manufacture of the long wool, alpaca, and mohair fabrics of Bradford, has at once established its superiority over the system of carding and combing by the old process. The contribution of machinery from the hands of such establishments as Platt Brothers & Co., and other English firms, are sure to be of unrivalled excellence. Several improved machines of the best construction, for the manufacture of cotton, were to be seen in the space occupied by the English. Messrs. Platt Brothers & Co. contributed a complete system of cotton-machinery; and Messrs. Elce & Co., of Manchester, did the same, with the exception of the blowing and spreading machines, which were not sent. Mr. Mason, of Rochdale, also contributed several exceedingly well-made machines.

The machinery for the manufacture of flax and silk was, however, very imperfectly represented in the English department, and, with the exception of the samples of yarn, there was nothing to point out the superiority of machinery in those branches of industry. This is much to be regretted, as for many years past we have taken the lead in the flax and the silk manufacture, and large quantities

of machinery, for both, have for the last fifteen years been exported to France and many other kingdoms of Europe.

Sir Peter Fairbairn, of Leeds, a large constructor of flax-machinery, is notable as having effected the greatest improvements, by his contributions, towards the perfecting of these machines; in fact, his machinery is to the flax-manufacturer what Mr. Whitworth's machine-tools are to the workshops. The reason assigned by him for not exhibiting, was the enormous expense of showing his very extended series of machines to advantage.

FLOURMILLS.

Thirty years ago the flourmills of France and most other parts of the Continent were of rude construction, and exhibited few traces of improvement from the constructions of the previous century. The corn-mills in England, Scotland, and Ireland had also been nearly stationary up to the same period of time, with the exception probably of some changes and improvements effected by Smeaton and the late Mr. Rennie. At the close of the last or about the commencement of the present century, the Americans and ourselves introduced the system of creepers and elevators, by which a considerable amount of labour was saved, and the operations of grinding, &c., rendered more complete. From time immemorial it has been the custom to drive the millstones from a large spur-wheel in the middle of the mill into which the stone spindles geared, and round which they were placed. This arrangement of the grinding process is still in operation in France and many parts of this country, and several exhibitors have given examples of some of their best mills constructed on this principle. Like those of this country, nearly all are continuous in the processes of cleaning the grain, grinding, and dressing the flour.

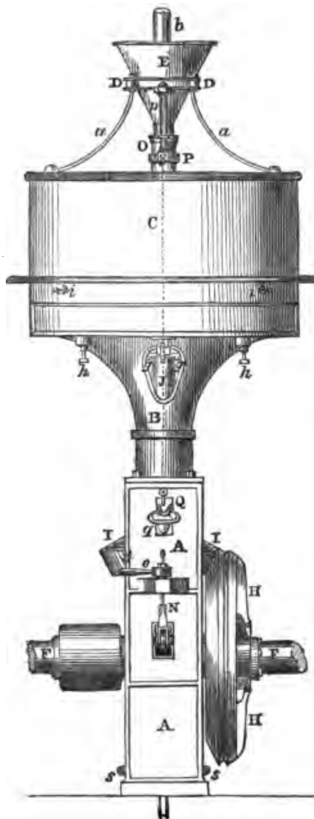
In France the millstones are generally driven by straps or belts, whilst those in England are almost invariably driven by gearing. It is upwards of *forty years* since Messrs. Fairbairn and Lillie, of Manchester, and some others in Yorkshire, first introduced the new system of placing the stones in a line, and driving them by bevel gear along one side of the mill; by this arrangement considerably increased space, for the convenience of stowage and other purposes required in the manufacture, was afforded. On this plan some of the best mills are now constructed; and although they differ from the French method of driving the millstones by straps, they nevertheless work with less power, are in many other respects preferable, and they do not crowd the room with belts in positions crossing the mills in almost every direction. It has been asserted that the straps are less expensive, and give a smoother motion; but of this there is much doubt, as the gearing, when properly constructed, is found to work perfectly smooth, and is less troublesome than straps.

The old method of feeding the stones was by a slide or spout at the bottom of the hoppers. This was a little inclined, and acted upon by what is technically called a 'damsel,' or, in other words, by a small spindle fixed upon the centre of the running stone, which passing upwards in the direction of the hopper, acted upon the slide by three projections or tappets, and gave it a noisy shaking motion.* This motion, and the rate of inclination at which the slide is fixed, gave the supply or required feed of grain to the stones.

About the same time, or shortly after the introduction of

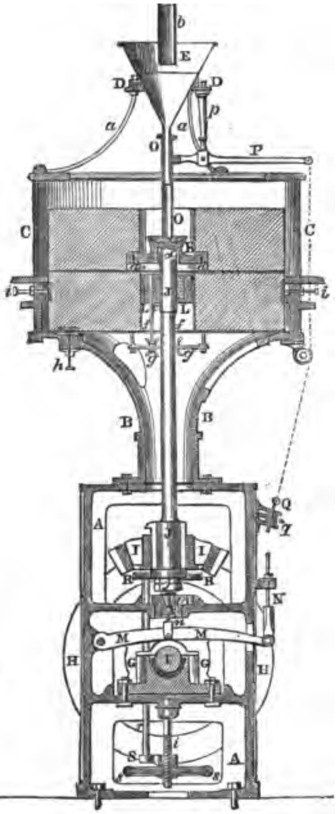
* The damsel was substituted for the 'clapper,' which in ancient times consisted of a piece of wood suspended by a twisted rope from the upper frame over the millstones. Thus placed, at every revolution it received a blow from a tappet, fixed into the back of the stone, and thus produced a vibratory motion on the shoe for feeding the stones.

Fig. 7.



Elevation.

Fig. 8.



Sectional Elevation.

THE GRINDING APPARATUS.

the plan of placing the stones in line, Messrs. Fairbairn introduced their new feeder, shown at K, fig. 8. The drawings, figs. 7 and 8, exhibit an elevation and section of a pair of millstones, showing the complete arrangement of the grinding apparatus, &c.

In this arrangement the stones are fed from the hopper E

by the tube O, about two inches in diameter, which conveys the grain into the cup K. This tube is suspended on the end of the lever P, and is fixed within a quarter of an inch from the bottom of the cup. As the upper millstone revolves, the cup goes round with it; and the tube being stationary, the grain escapes by centrifugal action, and is scattered in a thin stream from below over the edge of the cup, forming a beautiful series of oblique tangential currents as it passes into the eye of the stone.

This has been called the 'silent feeder,' owing to the total absence of noise; the quantity of feed being regulated by raising and lowering the tube by the hand-wheel Q and lever P. The lower part of figures 7 and 8 represent the horizontal shaft F, and the mode of driving the stones, as also the screw N, that regulates the space between the millstones by the lever M, on which the spindle and the running millstones are supported.*

The contributions to the corn-mill department of the Paris Exhibition were numerous and interesting, and the contributors showed no small degree of skill in the numerous forms and devices by which they respectively recommended their machinery to public notice.

A flourmill by Burdon, of five pairs of stones, and driven by a turbine, on the principle of Poncelet, deserves especial notice, from the novelty of its design, and the facility with which the stones can be stopped and started. The turbine with its cistern is placed below in the centre of the stones, five in number, and the main-shaft or spindle penetrates the first floor, and from thence ascends to the top of the mill, and in its passage gives motion to the different machines for dressing, cleansing, and elevating; it is, however, doubtful whether the novelty of this arrangement does not consist more in the ingenuity of the contrivance than in its utility.

* For a more complete description of this process, vide *Mills and Millwork*, Part II., second edition, page 148, *et seq.*

SPECIAL MACHINERY AND APPARATUS FOR WORKSHOPS.

The articles submitted to the adjudication of the jurors of Class VI. comprise a collection of such varied forms and character as to render any enumeration of them extremely difficult, and the distances by which they were separated from each other made it still more troublesome to arrive at a just and correct decision. The almost innumerable articles comprised in the class caused a division of the labours of the jury into sections, as follow :—

1. The separate pieces of machinery and apparatus for workshops.
2. Metallurgic machines.
3. Machines used in the preparation of timber.
4. Machines used in mining operations.
5. Machines used in agriculture and the preparation of elementary substances, including machines used in non-metallic minerals.
6. Machines used in the chemical arts and those in connection with dyeing and printing.
7. Machines used in the manufacture of metal.

I.—*The separate pieces of Machinery and Apparatus for Workshops.*

This section contained all descriptions of tools, screwing apparatus, copying and embossing presses, and implements of steel, iron, brass, copper, &c. In this section were assembled an immense variety of machines, which, from their magnitude, cost, and extensive developments, required the most careful attention.

The tools of Whitworth and others, and the machines for embossing, screwing, &c., were minutely inspected, and the opinions of the different members of the jury about them were given, with great judgment, on the spot.

Some idea of the extent of this collection may be formed when I state that not less than 400 articles were submitted to adjudication, some of them of great value, of exquisite workmanship, and comprising some highly skilful appliances admirably adapted for the purposes they were intended to serve. In Mr. Whitworth's collection, tools, lathes, and slotting machines of gigantic dimensions were to be found, some of them weighing from 10 to 12 tons, and a large lathe for turning wheels, with four rests cutting on both sides, with almost mathematical precision. These and others of smaller dimensions were neatly proportioned and admirably executed by the machine, and that without the aid of the human hand, beyond putting the parts together. Nearly, if not the whole of Whitworth's machines are executed in this manner; his screw-cutting machines, gauges, and other works are so well known as to require no description, and it is merely necessary to point out their presence at the Exhibition.

Next to Whitworth's tools and machines for turning and cutting metals must rank those of Graffenstaden, from the vicinity of Strasburg, for cutting and turning wood. These machines are beautifully and substantially made: they are mounted on cast-iron frames, and for ingenuity of design and perfection in execution they are not inferior to any other description of machinery in the Exhibition. Their mortising, boring and turning machines are admirably constructed, and the whole series appear to have been finished with the utmost care in order to meet the various requirements of every description of carpentry, cabinet making, &c.

Others, from America and other places, some of them of great ingenuity, were also exhibited, but none of them equal to those of Graffenstaden for solidity of construction and harmony in the proportion of the parts. To the American mechanics and engineers we are indebted for

ingenious and useful contrivances in this department of industry. Their pantagraph or *dummy* machines are admirably contrived, and no nations have applied more skill in the application of machinery to the cutting, carving, and shaping of timber than those of Canada and the United States. Their system of colonisation and the clearing of forests have given them facilities, and suggested inventions for saving labour, that could only be attained in a country where labour was scarce, and timber was the chief material for construction.

II.—*Metallurgic Machines.*

This section embraces a large field of operations, such as the forging and rolling of steel, iron, and copper. The machinery for blowing, smelting and the reduction of other metallic substances were present, and all the instruments and machinery used in the conversion of the metals from their crude state into the manufactured article were exhibited. Notwithstanding the great extent of the subject, and the number of machines classified under this head, the jury had not so much to do in this as in some other departments, as many of the machines, such as rolling mills, steam hammers, &c., were of great magnitude. Most of these were found exceedingly interesting, and evinced considerable skill in their adaptation to the attainment of the objects for which they were intended by the exhibitors. The jury in this, as in other cases, exercised a sound discretion in the awards.

From the variety of tilt and steam hammers exhibited, it would appear that the construction of those engines has been much cultivated in France; and notwithstanding the improvements and ingenious contrivances introduced by its inventor, Mr. Nasmyth, the French appear to have kept pace with us in the use and application of this im-

portant machine. Lately, Mr. Nasmyth introduced an invention by Mr. Wilson of the Low Moor Iron Works, a new, exceedingly ingenious, and, I believe, a very simple contrivance for working the hammer. By this application, any length of stroke, or force of blow, can be given by the operation of a single lever, and through this improvement the machine has attained a rapidity of action and a change of motion suitable to the powers of the engine, and the form or consistency of the articles under the hammer.* These improvements have not as yet been introduced into France, but the employment of so many large and small hammers, most of them well made, evinces a rate of progress in the operations of the forge as great, if not greater, than some of our best performances in this country. In the construction of vertical 'tups' or friction hammers, our continental neighbours have made much less progress, but they have exhibited clever contrivances in tilts, some driven by steam, and others by tappets through the intervention of gearing, and acting in the usual manner on the tail or hilt of the hammer.

Several French machines for the manufacture of nails were exhibited, but none of them indicated either novelty of conception or superiority of workmanship; on the contrary, I considered them inferior to the machines used for similar purposes at Birmingham and Wolverhampton.

In the machinery for slitting and rolling iron, there appears to be nothing new excepting some beautifully constructed steel rolls, manufactured by Krupp, and others of the iron manufacturers of France.

All the other machines of this class, such as wire drawing and cutting machines, were of the ordinary construction, with the exception of the American plate cutting machine.

* Vide Fairbairn's Iron Manufacture, 2nd edit., p. 133 *et seq.*

This machine consists of a strong cast-iron frame from nine to ten feet wide, having a steel plate along its outer edge on which the plate to be cut is fixed, and is held fast by a faller that rests upon the upper side of the plate. On the upper side of the frame a revolving steel cutter traverses its whole length, and in its passage cuts the plate in a perfectly straight line corresponding with the edge of the steel plate below. The circular cutter is an old invention, but its traversing motion is certainly new, and is effected by various ingenious contrivances. The travelling cutter, which requires considerable power when cutting thick plates, is driven by a pulley at the end of the machine.

III.—*Machines used in the Preparation of Timber.*

This section embraces every description of saw mill, planing, morticing, and tenoning machines, and all the tools, implements, &c., used in the preparation of wooden constructions. In this section were found a great number of interesting and instructive devices and adaptations, many of them of American origin, but greatly improved since their first introduction into European workshops. The treatment of timber, and the mode of seasoning, is a subject not clearly understood; much has yet to be learned: and the jury, fully aware of the difficulties which surround the question, entered into a careful inquiry as to the best methods now in use, and the most effective processes adopted in different countries for seasoning and rendering timber as strong and durable as possible under the varied conditions of quality and growth, and also the objects to which it can be applied. The jury appeared perfectly alive to the consideration that different qualities of wood required different treatment in seasoning, or such treatment as would consolidate their fibrous structure, strengthen their powers of

resistance to strain, and render them impervious to moisture and those atmospheric changes which so frequently affect the durability of structures composed of wood.

Of this machinery there were some excellent specimens in the shape of saws, cutters, planers, morticers, and groovers, which received careful attention in order to guide the jury in the award of the prizes and other marks of distinction to which the exhibitors were so justly entitled.

The most striking objects in this department were the saw mills, and those of Mr. Norman, of Havre, stood preeminent for the ingenuity and skill with which they were executed. His vertical saw for cutting timber of any required form for ship-building was admirably contrived, the movable frame on which the timber was fixed exhibited a variety of motions for giving any degree of obliquity to the cut, and thus, for ship-building purposes, the required twist or form necessary to be observed in the bows or stern of the vessel was easily attained without interruption to the cutting process by stopping the saw. Another vertical saw driven by steam power, in imitation of the hand-frame saw, and most ingeniously contrived, was also exhibited; its operations were very complete, and it formed one of a series of machines of great value in accomplishing the more intricate operations of cutting timber into shape. The steam saw frame of M. L. Schwartztrop, of Berlin, was also an exceedingly well executed machine. The steam cylinder is mounted on the top of a cast-iron frame, and the piston gives motion direct to the saw.* In this machine everything requisite to make it substantial was accomplished, and the traverse motions were well made and ingeniously contrived.

* This description of saw is an adaptation of one patented by Mr. Lang, of Johnstone, near Paisley, and has been in use in this country for many years.

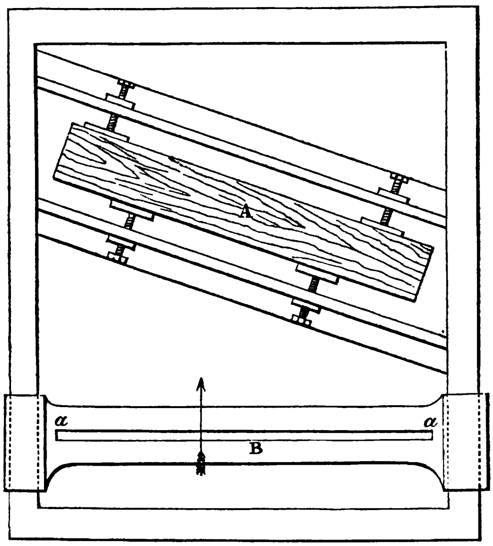
The greatest novelty among the whole group, however, was the belt or endless saw for cutting scrolls, squares, and circles of every possible curve. This instrument was so admirably contrived, that from its rapidity of motion, flexibility and continuity, it accomplished in cutting almost every description of form, and its vagaries (if I may use the expression) were so eccentric as to require a steady hand to guide and a steady eye to trace its operations in the lines of the cut, and some of these were so fine and so curiously curved as to puzzle the conception of the casual, and sometimes even that of the practised observer. The machine itself consists of a thin flexible ribbon of steel, almost three-quarters of an inch wide, and about the thickness of the blade of a lance, or a thin visiting card. The extreme ends of this ribbon, about 18 or 20 feet long, are run through two narrow slits of a table, and having passed over pulleys fixed at the top and bottom of the frame, it is brought into a state of tension by screws, and thus rendered workable by the application of steam or any other motive power attached to the axle of the bottom pulley. The table on which is fixed the article to be cut has a sort of ball and socket motion, which enables the operator to cut at angles from the vertical to any degree of obliquity which the nature of the work requires. This simple yet ingenious machine has been purchased by Colonel Tulloch for the carriage department of the Royal Arsenal at Woolwich, and its applicability to the purposes of preparing timber of intricate forms will, I make no doubt, prove equally beneficial in this as it is in ornamental cabinet work.*

The next machine, although not new, is nevertheless of some importance for cutting veneers; this is effected on the principle of the common hand plane. It consists of a strong cast-iron frame, on which slides another frame, to

* Since this was written, the Ribbon Saw has become generally useful in this and other countries of Europe.

which the cutter is attached. This cutter is so constructed as to plane or cut off the veneer at an angle of about 20°. In fig. 9, A is the timber and B the frame which contains the cutter. This frame moves in the direction of the arrow, shaving the timber in its passage to the required thickness of the veneer. The cutter or *plane-iron* is placed at a certain angle with the horizon, in order to

Fig. 9.



cut clean and deliver the veneer through the opening or slit *a a* in a perfectly sound and unbroken state. To prevent injury to the fibres of the veneer by tearing, and to deliver it free from cracks and flaws, it is not only necessary to keep the cutter perfectly sharp, but to steam the block, in order to prevent the veneer from tearing during the process of cutting, as it would in a dry state. Machines almost identical have been at use in Man-

chester and other places for years, in cutting the sides and bottoms of hat and pill boxes. Some of these machines will cut slices or shear shavings the whole length and width of the block, from the finest ribbon to one-tenth or one-eighth of an inch in thickness.

In the American department the model of a machine was exhibited for bending timbers for ships' knees, and every description of curved work employed in cabinet-making, joinery, &c. This machine, according to the inventor, Mr. Blanshard, has been used successfully in New York, and the consideration has been, how far it is applicable to other purposes besides those of ship-building and cabinet-making. Judging from the model and the full-sized specimens of ships' bows and stern-posts exhibited, the machine must be one of great strength, and although the piece of oak, ash, or other description of timber to be bent must first be steamed, it is clear that a piece of solid oak twelve inches square cannot be curved to a radius of four or five feet without the application of an instrument of great power. The apparatus having such work to perform consists of an exceedingly strong frame, to which the timber to be bent is fixed. One end is forced against a stop by a screw or a wedge at the opposite end, and the back or convex side of the timber being covered by a flexible iron plate fixed at one end to the stop, the plate as well as the timber is then drawn round by a capstan and chain at the opposite end of the desired curve, which varies in force according to the shape of the block round which it is bent. From this description it will be seen, that the fibres of the timber on the convex side cannot be torn asunder, so long as the plate is not elongated, and the plate on the back being pressed with great force against the whole surface, effectually prevents the starting of the fibres during the operation of bending. The result of this process is to secure the convex side

from fracture, and a crushing or sliding of the fibres into each other takes place on the concave side, which latter process is evident from the appearance of the crushed fibres, and the new condition and form it is forced to assume. It will be observed that the forces employed are chiefly those of compression, and that the fibres are not seriously injured by tension. In order that the timber may retain its form, it is not removed from the frame until it is quite cold and has taken a permanent set.

The machine appeared to be one of great importance when applied to the preparation of timber for ship-building and other descriptions of curved work extensively used in furniture and other works of utility and ornament. The inventor, Mr. Thomas Blanshard, of New York, has, I believe, applied the machine with great success to the bending of timber for plough handles, wheel felloes, and other purposes of utility.

IV.—*Machinery used in Mining Operations.*

In this section were comprised every description of engine tools, lifts, and parachutes used in mining, and especially those affording greater security to the miner, and for increasing the facilities and means of underground working, including those for subterranean transit and the raising of the mineral products at a cheap rate to the surface.

There are few subjects of greater importance to the community than that of the machinery for mines. So many of the comforts and enjoyments of civilised life depend upon the labours of the miner, that every discovery and every invention which tends to his advancement and security under the perils and hardships of his laborious life, must always be acceptable and justly entitled to reward. At the Paris Universal Exhibition, the machinery

of mines and other devices for assisting in mining operations were both numerous and instructive, and conceiving that a brief description of some of them may be useful, I shall endeavour to describe in detail a few of those which exhibited the greatest excellence and greatest ingenuity.

It will not be necessary to notice the larger machines and engines, such as those for pumping and winding; they are already so well known as not to require description here.

1. *Parachutes.*—An apparatus for preventing accidents in coal pits. The ancient method of raising coal from the bottom of the pit to the surface was by a basket, suspended to the end of a rope wound round the barrel of a windlass, worked by hand or by the horizontal horse gin. Since the introduction of the steam engine these primitive methods have given way to a better system, one of which is, by using one or more buckets or 'corves,' as they are called in the north, attached to each end of the ropes or chains, so that those at one end are descending whilst those at the other are ascending the pit. It not unfrequently happens that the ropes or chains which are used break, and the baskets or corves are precipitated to the bottom, and should any of the workmen be ascending or descending at the time, the result is attended with a serious loss of life. The present method of raising coal is a great improvement upon the old plan; it consists of four lines of iron rods, or, more frequently, wooden guides, which extend from the top to the bottom of the mine. Between these guides slides a wooden frame with two or more shelves, on which are placed boxes containing from eight to ten hundred weight of coal. These boxes are constructed to run on tramways through the workings, where they are loaded and sent forward, either by horse or manual labour, to the bottom of the shafts, and are

then at once run on to the shelves of the sliding frame already described; in this position they are raised by the steam engine to the top. They are then received by a movable frame, with a corresponding tramway, which slides over the mouth of the pit, and from this again they are run forward to the screens where they discharge their contents. It is evident that in our improved workings, great facilities are afforded for the raising of large quantities of coal in a short period of time; and in order to show with what despatch these operations are effected, I may refer to the colliery of Mr. Astley, at Dukinfield, near Manchester, probably one of the deepest mines in this country, where the coal is raised in four boxes, each weighing eight hundred weight, upon one rope, from a depth of upwards of 2,000 feet, at the rate of 20 miles per hour.

To prevent accidents in mines of this description, parachutes were invented; they generally consist of two strong iron blades, which in their working state remain at a short distance from the vertical slides. They are attached to the top of the cage, and in the event of the rope breaking, these blades by the falling weight and the assistance of a spring press forcibly against the slides, and thus by friction stop the cradle and prevent its falling to the bottom.

One of the parachutes made by M. Fontaine, of Auzin, had, it is said, saved the lives of thirty-seven persons, and in no instance has it ever been known to fail. In England, as well as on the continent, this description of apparatus is in general use, particularly in deep mines.

2. *Apparatus for raising Coal and the Workmen from the bottom of the Mine by the Pump Rods.*—This is not a new contrivance, as I believe it was first used in Cornwall, where the workmen to this day, in many of the copper and tin mines, continue to make their ascent and descent by ladders. M. Warocqué of Belgium, however,

exhibited a beautifully constructed working model of an apparatus to save this labour. It consisted of the shaft and pump rods with a series of platforms attached to the pump rods at every ten feet in height, that being the length of the stroke of the pumps. The pump rods move alternately, one being at the bottom of its stroke when the other is at the top. The baskets containing the material are run on to a platform which is raised by a self-acting apparatus attached to the pump rod to a height of ten feet, the length of the stroke; they are then transferred to the next ascending pump rod, which again lifts them ten feet, and so on alternately.

The transfer, both in the ascent and descent from the last to the next lift, was not only very ingeniously contrived but was effected with great precision. The raising or lowering of the workmen was effected by the same process, but with this difference, that they had to step from the ascending platform every time they arrived at the height of the stroke, and thus by a succession of lifts they arrived at the top. This very complicated process is greatly inferior to the plan of winding, which brings up the workmen and the coal at once from the bottom, saves all this complexity of motion, performs the work with five or six times the rapidity, and effects the whole operation with greater certainty. This apparatus failed in Cornwall, and from every appearance it is not likely to succeed in either this country or in France.

3. *Machinery for Washing Coal.*—I am not prepared to state to whom the public is indebted for this machine: I believe it is of English origin, and has been in use in this country for some years past with considerable success at the Cleator Iron Works in Cumberland, where I have seen it at work; it is also used in France at the Decazeville mines. It consists of two rollers, which crush the coal to a proper size, when it is collected in a

runner below, and from thence elevated to the washing machine above. This consists of several perforated plates, the first having holes about one inch in diameter, and the second about half that size. These plates receive an oscillating motion, and a stream of water being forced through the openings, a regular deposition takes place according to the densities of the different parts as they pass through the water in their purified state. Several of these machines are at work at Newcastle, Witham, Wales, and Wigan.

4. *Boring Tools.*—It is difficult to determine whether the apparatus for boring to great depths used on the Continent are superior or inferior to the apparatus employed in this country. Several ingenious tools of this kind have been brought into notice, such as those which cut out the core from the centre of the base. The recent improvements of Mr. Mather, of Salford, appear to execute this difficult process with the desired effect.

An apparatus constructed by M. Degorine was exhibited at the Exhibition and is calculated to bore from 200 to 2,000 feet. It consists of a small oscillating steam-engine, which works a windlass, and moves the boring rods by a cam for pounding hard homogeneous rocks; and it is also calculated to work at various speeds, according to the depths and density of the strata into which it penetrates. The tools themselves were exceedingly well made, of almost every possible variety of form; those used for deep boring, for catching and recovering broken rods, &c., deserve great praise for the skill and the ingenuity displayed by the maker.

It would be necessary, before venturing to express an undivided opinion as to the merits of the mining operations of France, Belgium, &c., as compared with those in which this country is engaged, to make the tour of Europe, and examine personally into the different methods by

which these objects are attained. Judging, however, from the different machines and apparatus contributed for exhibition, I am of opinion that there is probably no country where the operations of the miner are carried on to the same extent or the same perfection as in Great Britain. Here we have mines of greater depth and of greater extent than in most other countries, and we have probably greater experience, arising from the abundance of fuel and the advantages of steam power always at command.

II.

ON THE COMPARATIVE MERITS OF THE MACHINERY OF THE PARIS UNIVERSAL EXHIBITION—*continued.*

FROM the foregoing description it will be seen that the state of progress of engineering in this country, as compared with France and other states of Continental Europe, is not unfavourable to the skill and enterprise of Great Britain; and, following the same line of observation, I have to direct attention to the comparative merits of other machines presented for inspection at the Paris Exhibition of 1855. In this statement I purposely omit the machinery of agriculture, as a short abstract from the same Report to the Board of Trade will be found in the second series of 'Useful Information for Engineers,' page 162. In this section I shall therefore have to describe other machines of great beauty of design and of admirable construction.

TYPOGRAPHICAL MACHINES.

The mechanism of printing or typography has of late years been held in high estimation, and the rapidity, exactitude, and facilities which that department of mechanical industry now exhibits are, amongst many other improvements, the wonder and luxury of the age in which we live. The art of printing involves other considerations besides those of mechanical construction: it embraces the art of despatch in production, and contributes to the

widespread and rapid diffusion of knowledge. And it is no small boast that upwards of 50,000 copies of a daily paper like the 'Times' can be to some extent composed, printed, and distributed to the remotest part of the United Kingdom within a period of less than eighteen hours. Such, in fact, is the progress of mechanical typography; and the different machines and printing-presses contributed to the Universal Exhibition were no small indication of the progress made in the art of printing in France, in this country, and in other parts of Europe.

Typography is an art of such vast importance to the community, that it cannot fail to interest the observer and advocate of intellectual progress; and every improvement which tends to increase the facilities of rapid production in this art must always be acceptable to the economist, the politician, and the philosopher.

With these impressions the Jury entered upon the investigation of the numerous machines contributed by different makers to the Universal Exhibition. In this inquiry the Jury were ably assisted by M. Holm, the representative of Sweden and Norway in this department; and to the discrimination and sound judgment of that gentleman the Jury are indebted for an able investigation of the merits of most of these machines.

M. Holm was the reporter to this division in Class VI., and has exercised a sound discretion and great care in his inquiries into the peculiar properties and novelties of each machine; and, having accompanied him in his investigations, I am the better able to judge of the value of each machine taken separately, and the reward to which it is entitled. It is therefore with pleasure that I have to record the peculiar features of these machines, as they came respectively under the notice of the Jury.

The first of this class was a double or compound

machine, exhibited by M. Dutartre, of Paris, consisting of a typographical press for printing 'vignettes' and a machine for printing two colours on the same sheet. This machine is chiefly remarkable for the solidity of its construction, and the great attention paid to the working out of its details. In the motion of the tables several improvements have been effected; the oblique action of the connecting-rod being neutralised by an ingenious application of the guides, which effects a smooth and perfectly horizontal motion. This movement is obtained by a crank motion in connection with a fork-ended connecting rod, and by means of a toothed wheel, a motion at once alternate and rotatory is produced. This wheel, acting by an ingenious contrivance upon the upper and underside of a rack attached to the impression table, produces an extended reciprocating motion, four times that of the radius of the crank. The inking process is also well contrived, and a novel arrangement was observed in the roller and ink-box, to which M. Dutartre has added a supplementary roller. This is worked by a toothed wheel, and not only acts as an agitator in producing the necessary fluidity and mixture of the ink, but regulates the necessary supply, with the proper quantity and thickness of ink for vignettes. This process obviates the necessity of warming the ink to maintain its fluidity. The inking rollers are worked by wheels instead of bands as formerly used, which ensures absolute certainty of motion, and maintains perfect uniformity and fluidity in the ink-boxes. At the end of the machine is a table formed to receive the sheets as they are printed, and to clear the impression cylinder. If we consider the mechanical arrangements of the two machines, and the objects to be attained in the printing of vignettes and two colours by one and the same process, it would seem that this contrivance is well adapted for certain kinds of work.

Second.—M. Marinoni, Chevalier, et Bourlier, of Paris, exhibited a steam-press of four cylinders for printing newspapers, and a single cylinder press for other purposes. On examination the newspaper press appeared to be well constructed, and is calculated to print 6,000 sheets on both sides per hour. It is rather complicated, but with proper attention to the arrangement of the parts, it may be much simplified in its movements, and rendered a still more effective machine. It prints on both sides at once, but the sheets have to be cut in two, and on that account it requires four men to work the machine.

MM. Marinoni, Chevalier et Bourlier exhibited another machine for prints, similar to that of Dutartre as respects the movement of the impression table, but with this difference, that the table is supported on four rollers, which constitute the reciprocating movement of the press. This mode of moving the table is to some extent defective, as the only guides to the reciprocating movement of the table are the ends of the rollers, which are liable to wear and entail variation and uncertainty in a part of the machine which requires great accuracy in its movements. In other respects it is well executed, and is in high estimation among printers, who prefer it to most others.

Third.—M. Nicholais, of Paris, exhibited a continuous machine, with a cylinder calculated to cover a large surface, and approach as nearly as possible to a plane. The peculiarity of this machine is, that the cylinder works by a fixed rack (on the principle of Baker's mangle) attached to the table, and it is so constructed that it works only during the time it is in contact with the sheet, the period of rest being effected by the removal of a few teeth in the mortice-wheel, which produces the stoppage without retarding the progress of the other parts of the machine. In this way the table is reversed in and out of gear, and in such form as to suit the impression,

but not to stop the continuous movement and onward progress of the machine.

Fourth.—M. Normand, of Paris, exhibited a three-cylinder machine for newspapers, and a press. The machine for printing newspapers indicates an important improvement of recent date, by which rollers in combination with other rollers, that revolve by a peculiar movement, effect the printing on both sides of the sheet. All these movements are on fixed bearing, which renders the machine more effective in its operations and much simpler in its construction. The motion of the impression cylinders is obtained from a rack on each side of the printing-table; and the table is also moved by a rack and pinion fixed upon an 'articulating' axis. M. Normand claims the invention of this peculiar motion of returning the sheet upon one and the same cylinder, which he patented in the year 1848; but having neglected to fulfil the requisite forms required by law, the patent has become null and void, and is now the property of the public. Disregarding, however, the question of priority of invention and patent rights, the organic parts of the machine appear to be well constructed, and in perfect accordance with the operations required to be performed.

In the press, M. Normand has also introduced several improvements in the arrangement and adjustment of the pincers, which hold the paper to the cylinder when working, and give it the requisite position in the press.

Fifth.—M. Alauzet, of Paris, exhibited a machine for printing vignettes. It is well constructed, the parts being carefully developed, and it is remarkable for its solidity and superior workmanship. The table-movement is effected by the ordinary rack-motion, excepting that the teeth are of hardened steel. The impression-table is furnished with two distinct sets of apparatus, with four rollers to each set for spreading the colour, and the table,

rollers, &c., are of large dimensions, which gives solidity and greater exactitude to the performance of the machine.

M. Alauzet, finding it impossible to exhibit more than one machine, invited the Jury to visit his establishment, and to judge for themselves as to the merits and advantages peculiar to this construction. In that establishment the Jury found several ingenious movements and devices for simplifying and facilitating the process of printing, and amongst them a contrivance for giving the requisite pressure to the cylinder by means of eccentric curves placed above the axis of the impression-cylinder. A brush is also attached to keep the paper to the cylinder, and in order to ensure uniformity in the impression, hollow bronze rollers are used in some cases above the other rollers, to equalise and distribute the ink.

LITHOGRAPHING MACHINES.

MM. Huguet et Vaté, of Paris, exhibited a machine which greatly resembles the typographical press. It is worked by steam, and consists of a table, upon which the stone is placed, and the impression is obtained by means of a cylinder with regulated stops, moved by racks and worked by pinions, having an articulated axis attached to the impression-table. The platform or surface for the distribution of the ink is fitted to the impression-table, and the machine taken as a whole is nearly the same as the ordinary printing-machine, but with this difference, that there is just sufficient space between the circumference of the cylinder and the impression-table to admit the stone. When the stones are of different thicknesses, the required height is obtained by zinc plates; and to obviate any defects or unevenness of the surface of the stone, a thin piece of felt is interposed between it and the impression-table.

In working lithographic presses by hand, it will be observed that the workman has to moisten the stone with a water-sponge after the impression, and before the ink is applied. This operation is effected by MM. Huguet et Vaté by damping rollers, covered with cloth saturated with water. The motion of these rollers is very ingeniously contrived, and immediately after the impression is taken the rollers are raised by curved eccentrics, and the motion is so well timed as to prevent them touching the stone after it is inked. This application of the damping-rollers constitutes the novelty and superior efficiency of the machine; and such is the facility by which the impressions are taken, that 5,000 copies can be produced per day, while only one-fifth of that number can be executed by the hand-press in the same time.

MM. Dupont, Daret, et Carlier, of Paris, were large contributors in typographic as well as in lithographic presses. The former (three in number) are of great importance; and the fourth, although not equal to MM. Huguet et Vaté's machines, has nevertheless some points about it entitled to consideration. This machine may be used as a compound press, one half worked by steam and the other half by hand. Like other presses of the same kind, the stone is placed upon a table, and the impression is taken by a cylinder rolling over its surface. The table is moved by a rack and pinion, but the stopping and starting is effected by hand; and the process of inking, fixing the sheet, &c., takes place during the time the press is at rest. From this it will be seen that a great deal of valuable time is lost by this process; and although some attempts have been made to remedy these defects by steam rollers at each end for distributing the ink, the machine is nevertheless far from perfect.

Among other articles of the lithographic art was a

small portable press by M. Ragueneau, of Paris, which reproduces any kind of writing or drawing without transcribing the original on stone. This was done by simply writing the original, or what is wanted to be reproduced, on autograph paper with ink; it is then transferred to a metallic plate composed of pewter, antimony, and bismuth, fixed in a frame of the required size of the plate. The plate is inked by a roller in the same way as the lithographic stone, and a small tympan, or frame covered with leather, is attached to the block, and serves to cover the paper attached to the plate. The impression is taken by a small lever, which works the press by forcing the leather of the tympan upon the plate. The whole apparatus, with its inking-rollers, &c., is contained in a small box, the price varying, according to size, from 50 to 150 francs.

The articles contributed by M. Schnautz consisted of divers samples of his manufacture of lithographic impressions taken by rollers in black ink, and graduated tints of different colours. These rollers are composed of iron, covered with an elastic body of felt cotton, and this again with an envelope of leather (*chemise en cuir*), so neatly fitted as to render the jointing as nearly as possible imperceptible to the naked eye.

M. Brisset, of Paris, exhibited an iron lithographic press of the same construction as those generally employed in workshops for lithographic purposes. The price of M. Brisset's machine is 900 francs if the framing be of iron, and 600 francs if made of wood. This press has a supplementary framing, with transverse bars, and in these are point-holes for the purpose of adjusting the register when required to take more than one impression upon the same sheet. This arrangement of the parts is of some importance, as two or more colours can be taken by these means on the same sheet.

M. Thuvien exhibited a hand-machine similar to that used for letter-printing, and known as the 'Stanhope press,' but with the difference that the space between the table and the faller is sufficient to admit the lithographic stone in place of the type. In addition to this arrangement, M. Thuvien has established a supplementary plate of such thickness as to make up the difference of height suitable for lithographic impressions. The tympan of this press, like some others already described, has point-holes, which enables the operator to give different coloured impressions, similar to those produced by M. Brisset's machine.

MM. Cellerin et Devellier, Paris, contributed a machine for enlarging or reducing designs. It is very ingenious, and consists of a circular table with the edges rounded. Upon this table is stretched a sheet of vulcanised indiarubber, of about three millimetres thick. The edges or circumference of the indiarubber are drawn tight, and fixed to a circular ring, which regulates the caoutchouc by a screw which increases or diminishes the tension. Thence an impression taken when the caoutchouc is half stretched can be enlarged by lowering the ring, and vice versâ, the impression can be diminished by raising the ring. The impression of the design or the engraving required to be enlarged or reduced is first traced upon a sheet of gelatine or calking paper; it is then laid upon the vulcanised indiarubber, and when the size of the impression is fixed, two or three enlarged or reduced proofs may be taken, in their relative proportion the same as the original.

The utility of this machine is obvious in facilitating the operations of artists and designers for stuff-printing upon coloured paper, wood-engraving, and vignettes.

Messrs. Heim Brothers, of Offenbach, Grand Duchy of Hesse, exhibited a great variety of machines and

presses, remarkable for their cheapness and for the quality of the workmanship. Two-hand typographic presses were introduced, from which impressions are taken by a combination of levers; also a lithographic press from which impressions are obtained by a long lever and clutch fixed on one side of the press. This lever and clutch operate upon two shorter levers, one on each side, with connecting-rods across the *rateau.* The motion of the impression-table is effected by racks and pinions on each side of the press, and the whole of the operation is very simple, and may be established at a very small cost. In addition to the above, there are two presses for cutting paper, two others for giving impressions in relief upon skins, with the table resting upon springs. These are chiefly employed in bookbinding. A machine, with a curved knife, for cutting pasteboard, was also exhibited; the peculiarity of this instrument is the angle at which the knife is set, in order to place the edge in the most favourable position for the operation of cutting. Another press, with steel rollers, and table covered with steel plates for glazing and polishing, completes the series of Messrs. Heim Brothers' constructions.

In the department of Lithography, M. Busser, of Paris, exhibited a press of the ordinary construction, but with this modification, that the movement of the rubber *rateau* is effected on each side of the press, in order that the *rateau* should always be in a position parallel with the surface of the stone. The arrangement gives sufficient elevation for the movement of the *rateau,* but in ordinary presses, where the pressure of the *rateau* is produced from only one side of the press, it becomes necessary to use a spring on the opposite side, in order to obtain the required elevation between the *rateau* and the tympan.

It is much to be regretted, in this investigation of Typographical Machines, that none of a similar character

from this country or America were present with those of France and Germany. Such a press as that from which the 'Times' is printed at the rate of from 50,000 to 60,000 copies in a very short period of time, would have been highly valuable, and would have ranked in juxtaposition with those just described. It will however be remembered that every invention for perfecting these machines, and thereby obtaining facilities for increased rapidity in production, is of great public benefit; and, without depreciating the value of the machines submitted for inspection at Paris, it is more than probable that those of this country would have borne the test of comparison with credit.

MISCELLANEOUS MACHINES FOR VARIOUS PURPOSES.

It would prove an endless task to attempt a description of the immense variety of machines in this class. Those for the manufacture of hooks and eyes, grinding, compressing, and folding in paper chocolate cakes, washing, cleaning and corking bottles, cutting ivory, shell, and bone for combs, and machines and tools for the manufacture of brushes, may be enumerated as a sample of the curiosities of this numerous list.

The machine for compressing chocolate into cakes and folding it in paper coverings is a clever and most ingenious contrivance; it was designed by a young man from a verbal description given by his employer of the envelope machine, which he had seen at work at the Great Exhibition in 1851. Its operations in forming the cakes were well performed; and such was the exactitude of its motions in folding the paper and sealing it with red wax, that the human hand could not have done it with greater precision. The levers, pliers, and folders were equivalent to so many fingers, which handled the package with a

degree of certainty highly creditable to the ingenious contriver of the machine.

There was also a well-constructed machine for the manufacture of hooks and eyes; it was driven by steam-power, like the chocolate machine, and manufactures all sizes, from the largest clasp to hooks and eyes hardly perceptible to the naked eye. Like the cardmaking machine, it cuts and bends the wire, forms it into loops, and stamps it into the required form with the greatest rapidity and precision. It manufactures four or five times as many as could be made by the old hand-process in the same time.

Amongst other machines exhibited, that for moulding bevel, spur, and other wheels deserves particular mention. It is the production of our own countryman, Mr. Peter Jackson, and possesses the following advantages:—The ability to give to the teeth of each wheel a true epicycloidal or any other form that may appear advisable; great saving of time and expense in making patterns is effected, as a short segment only is required for moulding the wheel. It further enables the millwright to attain much truer wheels than could be produced on the old plan, and hence toothed wheels made by this machine may safely be run at much greater speed than those of the ordinary construction.

Fig. 10. (p. 172) is a vertical elevation of the machine, showing the moulding box and apparatus connected with it.

Fig. 11. (p. 173) is a plan of the machine.

It consists of a vertical spindle A, with a horizontal table or face-plate B upon it; this spindle works in the conical bearing formed in the frame C. The foot of the spindle B is supported by four diagonal struts D D, extending downwards from the frame C which supports the table B, and everything that is laid upon it by means of the footstep E, by which the table can be raised at pleasure

Fig. 10.

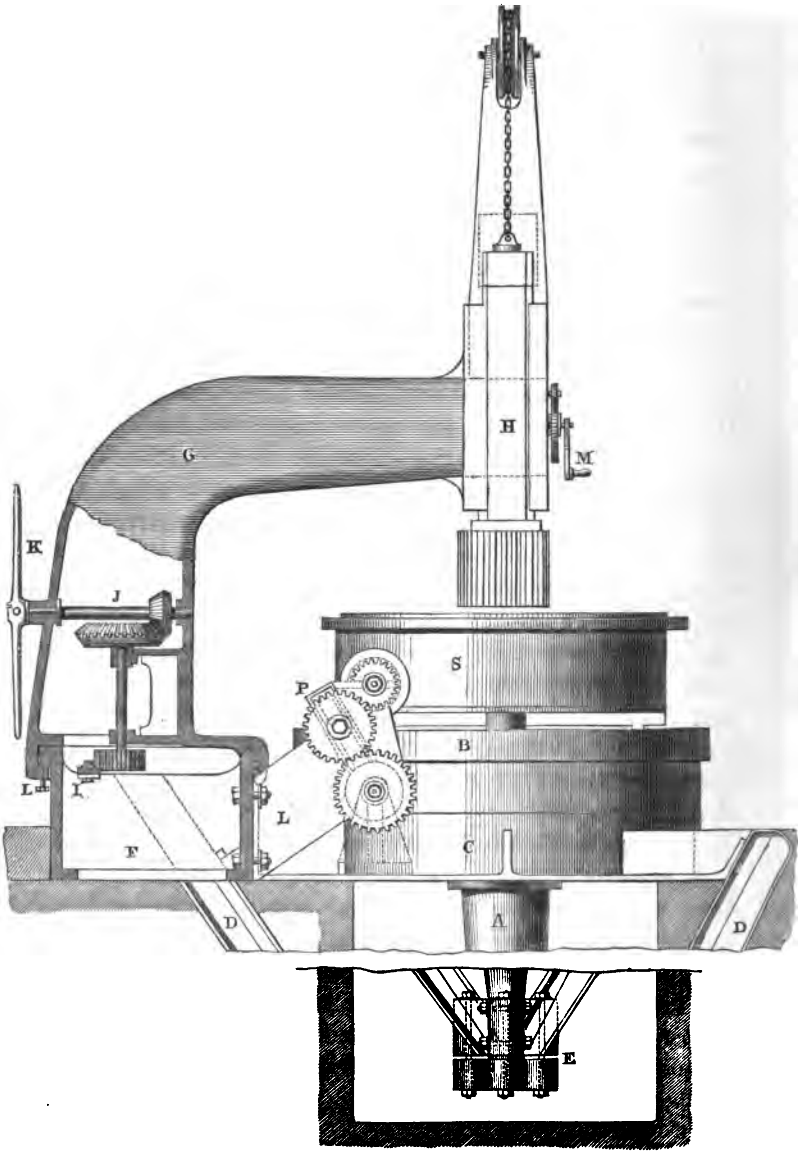
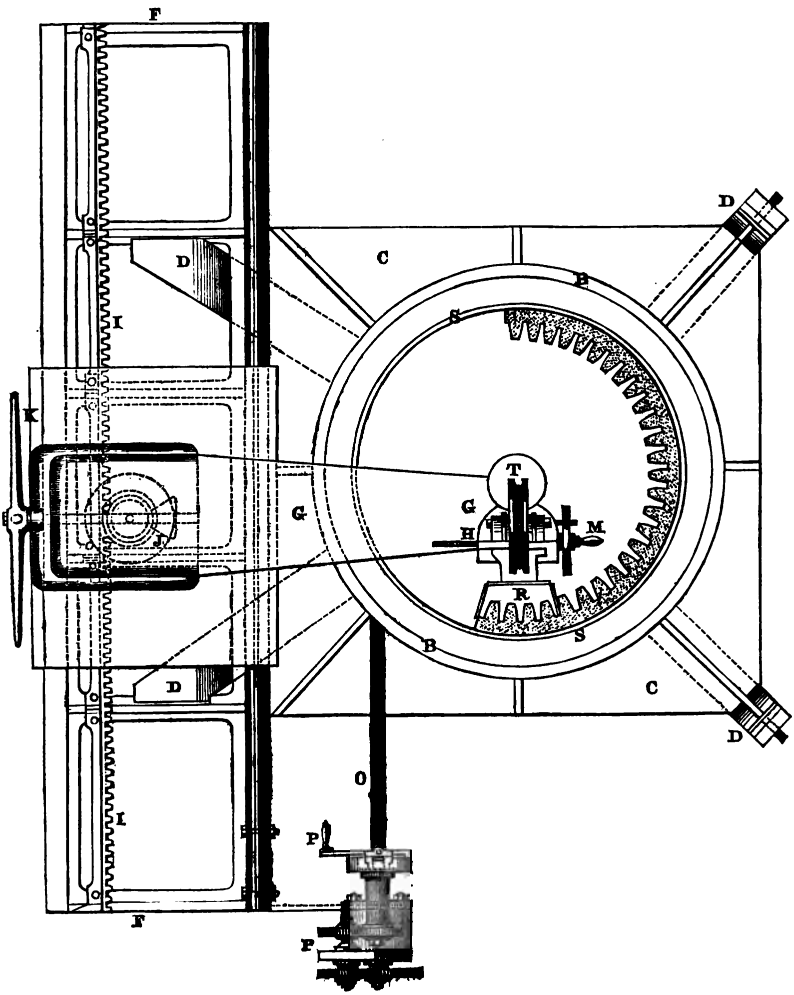


Fig. 11.



in the conical bearing in the frame C, thereby enabling the workman to turn the table round with very little force and perfect steadiness, though bearing a great weight.

F F is a horizontal slide-bed attached firmly to one side of the frame C; upon this slide is moved the sliding-jib G, carrying at its extremity the vertical slide H. A rack I I is attached to the slide-bed, into which works a pinion on the shaft J, driven by bevel-wheels and the cross-handle K. By means of this apparatus the vertical slide H can be placed in any position over the table B, or removed clear from it on either side.

The set screws L L are for the purpose of fixing the sliding-jib firmly upon the bed, and holding it in any position that may be required.

The vertical slide H is moved by a rack and pinion worked by a handle and shaft M, and is rather more than counterpoised by a weight T attached to a chain passing over a pulley at top. A rachet-wheel with pall is fixed upon the handle M, to hold the slide from being drawn up by the balance-weight, or forced up by the moulder; and the balance-weight is made a little in excess, so as always to insure a pressure upwards against the rachet.

A worm-wheel is fixed upon the underside of the circular table B, and is worked by the worm and shaft O, turned by the handle and change-wheels P, similar to an ordinary dividing or wheel-cutting engine. By turning the handle P the required number of times, having previously adjusted the change-wheels to suit the number of teeth in the wheel intended to be moulded, the circular table B is moved round an interval equal to the pitch of the wheel, and this movement can be accurately repeated through any part of the circumference.

The short segment pattern of the wheel to be moulded being attached to the vertical slide H, and the moulding-

box to the table B, the segment pattern is brought down by the slide till it rests on the levelled sand intended to form the bottom of the mould, the top of the segment being level with the edge of the moulding-box; the moulder then rams up in the ordinary way that portion of the box opposite the segment pattern by means of the slide H, and then turns the circular table B, by the handle P, through an interval equal to the number of teeth contained in the segment pattern; the pattern is then again lowered and the ramming-up of the mould proceeded with in the new position of the box; and this process is repeated till the whole wheel is moulded.

MACHINES FOR SETTING-UP AND DISTRIBUTING TYPE.

Three of these were exhibited, two from Belgium, and one from Copenhagen. One of the Belgian machines was for setting up, the other for distributing, by the movement of keys alphabetically arranged. In the Copenhagen machine, invented by Mr. Sörensen, these two operations were performed by one machine, the distributor being above and the composer below. All these machines exhibited great skill and ingenuity in the arrangement of the grooves or conduits for conveying the types to the composer as they were struck off by the distributor. Mr. Sörensen's machine consisted of a cylinder about sixteen inches in diameter, the upper part of which contains grooves in which the type is arranged. From this part of the cylinder they are dropped into their respective grooves by action of keys, like those of a pianoforte; as the compositor spells the words the grooves convey them to the composing-stick, and arrange them side by side. All the type was of the same length and thickness, and the machine is admirably contrived to insure their falling with their heads up into the channels which convey them

to the composing-stick, where they are divided into lines according to the size of the page. M. Sörensen's machine was beautifully made, and its operations, in the hands of its inventor, were highly satisfactory, and well deserved the commendation of the Jury.

CONCLUSION.

It is to be regretted that we have no statistical accounts on which reliance can be placed, of the condition of the working-classes abroad, as compared with that of the English operatives; judging, however, from what I saw of the population of Paris and other parts of Europe after the peace of 1815, and during several subsequent visits, I should infer that the whole working population of the capitals and large manufacturing towns of both countries, has undergone a considerable change, and is still in a state of transition. The increase of manufactures of all kinds, and the earlier introduction of railway communication have rendered this change more strikingly apparent in our own than in foreign countries, and the population of Great Britain has already felt, and in some degree accommodated itself to, these influences, which abroad are only beginning to produce their results; and on the Continent the effects of a transfer from one system of operations to another are now developing themselves.

The French *ouvriers* are active, intelligent, and well employed—the Germans, Swiss, and Belgians, patient and enduring: and although foreigners may take a longer time in executing work than English workmen, they are nevertheless expert, and in many cases better educated, and therefore better able to cope with the difficulties and surmount the obstacles in the way of a successful progress.

I do not mean to intimate that the mass of the workmen abroad are better educated or better informed in the practice of their respective callings than in England, but I firmly believe from what I have seen, that the French and Germans are in advance of us in theoretical knowledge of the principles of the higher branches of industrial art; and I think this arises from the greater facilities afforded by the institutions of those countries for instruction in chemical and mechanical science.

When reporting on the manufacture of iron, I endeavoured to show that, notwithstanding the natural resources placed at our disposal, the quality of our cast iron is not to be depended upon, that under the powerful stimulus of self-aggrandisement we have perseveringly advanced the quantity, whilst other nations, less favoured and less bountifully supplied, have been studying with much more care than ourselves the numerous uses to which this material may be applied, and are in many cases in advance of us in quality.

I also adverted to the advantages of the employment of iron as a building material, and pointed out that the education of that important class of men, mechanical architects, who give character to the taste of a community, is behind that of other countries. The architects of Great Britain have not availed themselves of the use of iron in construction to the extent they might have done; and it is somewhat surprising that it should be so energetically and profitably employed in buildings in France, where its cost is nearly double what it is here, and is a reflection on the intelligence and enterprise of a profession that has always stood, and I hope will continue to stand, high in the estimation of all who wish well to their country and to the advancement of the industrial arts.

Several ingenious contrivances have from time to time been brought forward by our Continental and American

competitors in machinery for the manufacture of textile fabrics, and a friendly rivalry has always existed amongst the contributors to this department, which has had the best possible influence on the progress of manufacturing industry. Great Britain has assuredly every reason to be proud of the position she holds in regard to this division of the mechanical sciences; to maintain it she must exercise the same skill and indomitable perseverance which have marked her past career; and so long as the same inducements are in operation, and similar encouragements for active exertions are held out, her spirit of enterprise and energy of execution will lead to the best results.

I have already expressed my opinion of the great progress that has been made in the construction of steam-engines, iron bridges, and machinery, wherever the railway has made its appearance. In this department, however, our superiority is not so strikingly marked, and although we still take the lead, we are not much in advance of others, as the engines exhibited at Paris fully proved. In marine constructions we are still superior to all other nations; but abroad rapid advances are making in that direction also, as was evidenced by the engines of the Mortala Works in Sweden, which were admirably made, both as regards simplicity of form and compactness of construction.

In the construction of millwork this country stands unrivalled; and although repeated attempts have been made to imitate the transmissive machinery of our manufacturing districts, they have not been as successful as might have been expected; and our millwrights stand alone for neatness of design and judicious proportion of the parts of the transmissive machinery employed in all the branches of that useful department of industry.

In the manufacture of tools for workshops we are also

unequalled, as with one or two exceptions the tools of foreign construction will not bear comparison with those of this country. The same cannot be said of the lighter descriptions of machinery and instruments of precision; in many of these constructions the French, Germans, and Swiss are even in advance of the manufacturers of this country.

With the exception of reaping-machines, in which America excels, our agricultural implements, including those for working plastic materials, are superior to those of most countries, and this superiority appears to be due to the variable nature of our climate, which necessitates an improved system of culture and the use of machines calculated to save time and to insure success in the labours of the farm.

In conclusion, it only remains to state that the Paris Universal Exhibition of 1855 and that of London in 1851 have produced their proper effects. They have shown to the world, in every department of industry and of practical science, wherein consists the prosperity of nations and the happiness of mankind. They have shown how all materials, whether derived from the forest, the field, or the mine, may be turned to purposes of utility; how the labour of man may be multiplied a thousandfold: how the fruits of the earth may be cultivated and gathered in for man's necessities; and how works of art may be elaborated to increase the happiness and enjoyment of his existence. All these things were exhibited on a scale commensurate with the greatness of an undertaking so vast in extent, so varied in form, and so characteristic of all the duties and wants of human existence, as to elicit the admiration and praise of astonished multitudes from every country of the civilised world.

III.

ON THE MACHINERY DEPARTMENT OF THE INTERNATIONAL EXHIBITION OF 1862.*

No section of the Great Exhibition afforded a deeper interest to all classes of the British public than the Department of Machinery.

Whilst in other divisions it was the object of our Continental neighbours to excel, it was evident all they could hope to do in the province of mechanical engineering was to stand on the same level, and compete with us in a friendly rivalry of skill in constructive art. In many instances they succeeded; but we believe that every competent judge of the subject who visited the Exhibition, and every reader of the following remarks, will agree with us in thinking that, notwithstanding the rapid and creditable progress made elsewhere, Great Britain still holds the proud position of being at the head of nations in mechanical appliances and engineering proficiency.

In order to enable our readers to form a clear conception of the advanced stage to which the mechanical operations of the engineer have attained, it will be necessary to examine—

1st. The sources from which we obtain the elements of motive power, comprising the steam-engine, its varieties, forms, and application.

2nd. Water-power, as exhibited in water-wheels, turbines, and other hydraulic machines.

3rd. Grinding, crushing, and cutting machines.

* Abstract from Mr. Fairbairn's Report.

4th. The machinery for the manufacture of textile fabrics.

5th. Locomotive machinery and railway plant.

Lastly. The machinery of agriculture.

As an introduction to these divisions of our subject, we would observe that we have for the source of all power the heat of the sun, which, according to the new theory of Professor W. Thomson and Mr. Waterton, is produced and maintained by a constant shower of meteoric matter falling into that luminary. If we assume this to be true, it then follows that this continuous flow of matter will produce cosmical heat, which acting upon the surface of the earth stimulates the growth of plants, and these again employed in the shape of fuel are converted into mechanical force, which, united to other contrivances, abate the necessity for muscular exertion in man and animals. To the same source may be traced the vivifying principle of animal and vegetable life; and the deposits of past ages, now in use as agents of accumulated force, are those which constitute, in almost every case, the necessary provisions for obtaining power in the shape of mechanical force.*

Steam-engines are the most important agents now in use as motive power in Great Britain, and from these alone we receive nearly the whole of the force at present operating in manufactures, steam navigation, locomotion, and mining. They are of three classes of engines,—Stationary, Marine, and Locomotive; and these are again subdivided into Condensing and Non-condensing Engines. Nearly all of them at the present time work the steam expansively; that is to say, they are so arranged in the construction of the valve motions as to cut off the communication with the boiler at one-eighth to two-thirds of the stroke, as the case may be, regard being had to the

* For the two principal laws of thermo-dynamics, *vide* page 97.

pressure, or power necessary to overcome the resistance of the load. Some engineers go so far as to cut off the steam at one-sixth and one-eighth, and expand the remaining five-sixths or seven-eighths of the stroke. The expansive system is now thoroughly understood, and is in almost every case resorted to, with a great saving of fuel. Of late years the principle of expansive working was very imperfectly understood, and the result of its introduction was an immense economy; for more than double the quantity of work is now done with the same quantity of fuel, of what was formerly accomplished on the old non-expansive principle. It must, however, be borne in mind that this cannot be effected without an increase in the pressure of steam, and hence follows the necessity of having the boilers of increased strength and improved construction.* The neglect of these precautions has resulted in serious and fatal accidents, attended with considerable loss of life and property.

Irrespective of increased pressure, and working the steam expansively, the speed of the engine has been increased about one-third since the days of Watt. In his time the piston of the stationary engine travelled at the rate of 240 feet per minute; now it averages from 300 to 350 feet, and on some occasions to 400 feet, and this, combined with high-pressure steam worked expansively, increases the power of the engine, in some cases, upwards of twofold, and, as already stated, doubles the quantity of work done with the same quantity of fuel. Thus an important saving is effected to this and every other country where steam is employed as the agent of motive force.

The Exhibition of 1862 does not present any new or original conception in the construction of stationary engines, with the exception of the non-condensing engines,

* *Vide* page 105.

which, in this case, have their cylinders horizontal instead of vertical, as exhibited in the old construction. There are some advantages in this, as the cylinders of the non-condensing engines are comparatively small, and are less liable to wear oval than would be the case in the large condensing engines. These engines are, however, chiefly used as assistants to the stationary condensing engine, and effect a saving by the steam being employed twice over, for it first propels the piston of the high-pressure horizontal engine, after which it is conveyed to the cylinder of the large condensing engine, where it finishes the work at a considerably reduced pressure.

These double engines are mere substitutes for the compound Engine of Woolf, with this disadvantage, that considerable loss is sustained by condensation in conveying the steam from one engine to the other; and, taking into account the back pressure and other causes, this combination is less effective than the united compound engine. But exclusive of these drawbacks, it is found in practice that the non-condensing engine does nearly the whole of the work, and in many instances drags forward (if we may use the expression) the piston of the old condensing engine along with it. The work done by the larger engine is, therefore, nil, or little more than what is gained by vacuum and condensation. In the Woolf or compound principle, this is not the case to the same extent; but it yet remains to be solved what benefit there is in a more expensive and more complicated construction, when the same advantages can be obtained by the single cylinder.

That is the question for solution, and to which the advocates of the double cylinder reply, that in working with high pressure steam the force applied to the piston of the first cylinder is diffused over a much smaller area, and the action is less severe upon the working parts of

the engine than if forced, with the velocity of impact, upon the surface of a greatly enlarged piston, as in the case of the single-cylinder condensing engine. This, to a certain extent, is correct, only it does not affect its working economy, but simply the strength of the working parts of the engine. Again it is stated that the double-cylinder engine produces from the same cause a more uniform motion than the single-cylinder engine. But the advocates for the single-cylinder system affirm that these objects are all attained, first, by cutting off the steam at a point that will produce the same rate of expansion as in the compound engine, and this, although suddenly effected, is fully compensated by the action of the fly-wheel, at the greatly increased speed of the engine.

We have been the more particular in this description as the question is not yet settled among practical men which of the two systems is the best; each side has its advocates, with proofs which they adduce in confirmation of their respective theories. Without entering further into this question, we may, however, state that we would prefer the single-cylinder engine, where the advantages are the same as those of a more complicated form; for it appears to us that no benefit is gained in the shape of economy by the double or the compound engine; on the contrary, we are inclined to believe there is a loss in the former, owing to the difficulty of working them together as one engine. The same reasoning will apply to what is called the M'Naught principle, which consists in placing a high-pressure cylinder at half-stroke under the main working beam of the ordinary condensing engine, and exhausting the steam from one cylinder to the other, on the same principle as already described in the double, horizontal, and vertical system.

Having described the different forms and conditions of

our stationary engines, and the improvements that have been effected by the introduction of high-pressure steam worked expansively, we may conclude this part of the subject by observing, that we are far from arriving at that point of economy in the use of steam which an increased pressure and a still greater expansion is calculated to attain. It is true that the danger of boiler explosions may be increased, and so it would with our present means; but in our locomotive engines we already work steam at 200lb. pressure on the square inch with greater safety than is done in our stationary engines at a greatly reduced pressure; it is, therefore, evident that we are behind in this department, and a wide field is still open for improvement. It is not our province in this article to point out how this can be accomplished, but we may safely affirm that the improvements already attained are only the precursors of others of much greater importance in the economy and use of steam.

Marine Engines.—In this department of constructive art this country stands pre-eminent in advance of all others at the Exhibition. It is not the principle nor yet the power that attracts notice, but the application, design, and construction of a machine calculated to propel a vessel of 6,000 tons burden, at a rate of from fourteen to fifteen knots an hour, and yet so small and so compact, compared with the magnitude of its force, as to excite the admiration of every beholder. In this department of mechanical science we have, concentrated within a space little more than twenty feet square, a force equivalent to 2,600 indicated horses' power, and that with all the conveniences of approach to every part of these powerful machines.

For examples of engines of these colossal dimensions and compact form, we have only to refer the reader to those of Penn, Maudslay, Rennie, Humphries, and others,

to convince him of the superiority of their construction, the mathematical accuracy with which they are designed, and the precision with which they have been manufactured. In these respects they are superior to anything before accomplished in this country. Several specimens of a different kind have been exhibited from France and other parts of the Continent; but they are not the best examples of the industry of those countries, excepting some small engines from Sweden, and a beautiful double-acting engine for river boats, by Messrs. Escher & Co., of Zurich. As a whole, the marine department has been well represented by engines of great power, and working models (chiefly by Maudslay & Field) of great beauty.

It is not our intention or we might have entered more into detail, and illustrated the various contrivances of the working parts; under the circumstances, we have to confine ourselves to the following outlines of the different types of marine engines, as exhibited by the different makers, showing the space they occupy in the ship, length of cranks, &c., as given in figs. 12, 13, 14, and 15, taken from Mr. Mallet's report in the *Practical Mechanics' Journal.*

From the above it will be seen that fig. 12, with the double piston-rod and reversed connecting-rod, occupies the least space in length; fig. 14, with a three-crank connecting-rod, the next; and subsequently follow in the order of length; fig. 13, trunk engine, and, lastly, fig. 15. Mr. Mallet classifies them differently by taking the crank as the unit of measure; from which it follows that the direct acting-engine, with short connecting-rod, occupies a much less total length than either of the others. This saving of space on board ship is always a desideratum in the construction of marine engines, and is a point carefully attended to in the British navy.

Most of the engines are of the screw-propeller kind,

and the specimens exhibited are certainly of the highest order, whether as regards design or workmanship. The working parts are chiefly composed of wrought iron with a link-motion for working the valves. Paddle-wheel engines are not exhibited, excepting only in models, and a pair of oscillating engines, including drawings and

FIG. 12.

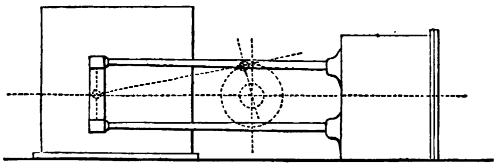


FIG. 13.

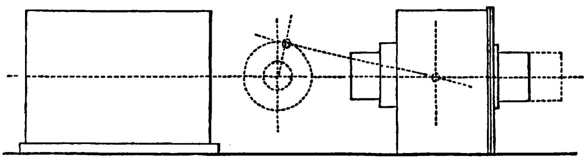


FIG. 14.

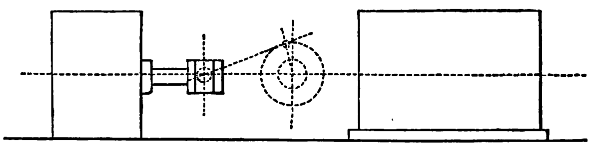
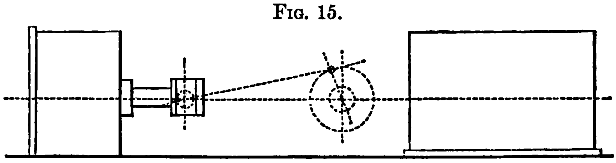


FIG. 15.



models of Maudslay's annular cylinder engine. Most of these have been in use for years, and are, therefore, deficient in novelty when compared with the more compact form of the screw-propeller class. Altogether the Exhi-

bition in this department is replete with admirable specimens of marine constructions, and we have only to instance the 600 nominal horse-power engines by Penn, and the 800 horse-power by Maudslay & Field for the iron-plated frigate *Valiant,* with others of less power, to be convinced of the wonderful development of mechanical science in this age of progress.

To marine constructions we have to add a great variety of vertical, horizontal, and angular engines, adapted to almost every possible purpose where power is required. Some of these engines have double, high, and low pressure cylinders, with and without condensers; others are single cylinders of peculiar construction, and exhibit several new arrangements accompanied with surface-condensation * and other contrivances for superheating steam † and preventing the escape of heat. All these are improvements on the past; but those which have been effected during the last seventy years (although valuable in themselves) are not such as affect the general principle arrived at by Watt, and subsequently perfected by the same comprehensive intellect that made the steam-engine what it now is, the strong arm of power and the hard-working agent of civilised existence.

Water Power.—Half a century has scarcely elapsed since water was the prime agent as a motive force. To that element, and to wind, we had recourse when power was required for the purposes of mining, agriculture, or manufacture; but the limitation of supply and requisite height of fall required for power were so great, and so uncertain, as to cause frequent stoppages of the works, and to spread them widely distant from each other

* Surface-condensers are vessels in which the steam is condensed by pumping cold water on to the exterior surfaces of tubes through which the steam passes.

† Steam is superheated by the pipes containing the steam passing through flues or vessels heated with air at a high temperature.

over the face of the country. At the commencement of the present century, when the improved machinery of Arkwright and Crompton created a demand for power on a large scale, the whole of the river and mountain districts were searched for suitable sites for mills; and for a series of years it was found necessary to take the mill to the power, and not the power to the mill, as it has been since the introduction of steam. In some countries it is still desirable to employ water as a moving power, and hence follow the numerous improvements that have taken place in the construction of water-wheels, turbines, and other hydraulic machines. As late as 1830 water-power was still in demand in this country; but from that time to the present it has been considered of little value unless it be in some districts where the power is considerable, and where the weirs, aqueducts, and mill-dams already exist. For a number of years the mills for cotton, corn, and flax, were turned by water, and the construction of water-wheels was greatly improved by making them entirely of iron, which took place at the beginning of the present century. The late Mr. T. C. Hewes was one of the earliest improvers of water-wheels on the suspension principle, and this was followed by a new system of ventilation, by which the buckets were relieved of air on the entrance of the water, and subsequently restored at the lowest point of discharge. By this ingenious but simple contrivance the duty of the water-wheel was raised to a maximum, and the construction of water-wheels composed of iron arrived at a very perfect state. It was at this time that the investigations of Poncelet and the perseverance of Fourneyron introduced the horizontal wheel, founded on principles established by the former and adopted, after careful experiments, in the shape of the turbine by the latter. For several years the turbine made slow progress, as its advantages were not superior to that

of the water-wheel, which maintained and still retains its reputation in regard to the amount of work done with a given quantity of water. The turbine, however, occupied less space, was somewhat cheaper in its original cost, and became general on the Continent and America. Of late years the turbine has been greatly improved in this country, and we have several admirable specimens in the Exhibition, a few of which it will be proper to notice.

In every description of machine—recipient of water—it is a universal condition that the water, to attain its full efficiency, should make its entrance and take its departure at a slow velocity. This has never been done with the turbine, but a close approximation has been attained by the best-constructed water-wheels. Smeaton, in his experiments on water-wheels, attained something above 80 per cent. of the theoretical fall, and some of the best wheels of the present time have arrived close upon that point of efficiency. Now, the best-constructed turbines seldom exceed from 65 to 70 per cent. There are, however, certain advantages peculiar to the turbine which do not belong to the water-wheel; namely, that it can be made to work waterfalls of from 300 to 400 feet in height; and what is of considerable importance as regards efficiency is that it works well in back-water.

There are three different descriptions of turbines.

1st. Turbines in which the water passes vertically through the wheel.*

Wheels of this class are composed of two annular cylinders, the upper fixed and the lower revolving on a vertical axis. The upper is fitted with guides to direct the water most efficiently against similarly curved vanes or buckets, turned in the opposite direction, in the lower wheel. The water passes from the reservoir or cistern, placed over the upper cylinder, vertically downwards, acting on the re-

* *Vide* 'Mills and Millwork,' Part I., 2nd edition, page 158 *et seq.*

volving wheel by pressure as it glides over the surface of the vanes. Burdin, about 1826, invented a turbine of this description (*turbine à évacuation alternative*), the efficiency of which was about 67 per cent. of the theoretical fall.

2nd. Turbines in which the water flows horizontally and outwards.*

In turbines of this class the revolving wheel is placed outside of the fixed wheel, so that the water directed by guide-plates on the inner wheel strikes the curved vanes of the outer wheel, and forces them round by pressure and reaction. The water is regulated by a cylindrical sluice fitting between the fixed and movable wheels.

M. Fourneyron's turbine is the chief example of this class. Its advantages, as stated by M. Poncelet in his report to the Academy of Sciences at Paris, are the high velocity at which it may be worked without reducing its useful effect, its small size, and, lastly, its capability of working equally well under back-water. From the experiments of M. Morin, the co-efficient of useful effect † appears to range from 0·60 to 0·80. On the other hand, it has to the full the defects of this class of machines, requiring the utmost nicety of design and execution, and being very susceptible of injury from small bodies carried into it by the water. It requires for its successful application both a large acquaintance with the principles of its construction and a considerable experience of its use.

3rd. Turbines in which the water flows horizontally inwards; vortex wheels.‡

We owe the invention of this class of turbines to Professor James Thompson, C.E., of Belfast, and probably no turbines are more efficient or capable of more general

* *Vide* 'Mills and Millwork,' Part I., 2nd edition, page 162 *et seq.*

† The coefficient of useful effect is the percentage of the power expended as compared with the work accomplished.

‡ *Vide* 'Mills and Millwork,' Part I., 2nd edition, page 166 *et seq.*

application to every variety of fall than the vortex wheels which he has constructed.

The peculiarity of these vortex wheels consists in the arrangement of the fixed guide-blades on the outside of a circular chamber, in which is placed the revolving wheel, so that the water flowing inwards strikes the curved plates of the revolving wheel tangentially, and leaves the wheel at the centre at a minimum velocity; the whirlpool created in the wheel-chamber giving to this description of turbine its designation of vortex wheel. These wheels are constructed by Messrs. Williamson & Brothers, of Kendal, who, we believe, have at present erected all that are employed in this country.

In addition to the horizontal wheel or turbine, there are centrifugal pumps and water-pressure engines. The first and most important is by Mr. Appold, and to that gentleman the country is indebted for many ingenious mechanical contrivances. Messrs. Gwynne have also contributed to the centrifugal pumping system, and both show splendid specimens of their different constructions at the Exhibition. This machine consists of a small wheel or fanner with blades, which is driven by steam power at a great velocity,—as many as from 800 to 1,000 revolutions per minute, at the bottom of the suction-pipe. This wheel, revolving at great speed in a tight box, forms a vacuum in the suction-pipe, and thereby forces the water before it, up the discharge-pipes to the required elevation.

These machines are simple and effective where the water has not to be raised to a great height, but they are inapplicable for high lifts, and require a considerable amount of power to overcome the friction and pressure of water in the pipes. It is a question yet to be solved as to whether they are equal, on the score of economy, to the common pump. In fact, they are the same as a scoop wheel surrounded by water in a close box.

Those who have witnessed the imposing effect of these machines at work in the Exhibition cannot be otherwise than struck with the large body of water which they discharge to a height of 12 or 15 feet. Without, however, entering into comparison as to cost or the force employed to raise a given quantity of water, we arrive at the conclusion that this system of raising water is well entitled to consideration.

The water-pressure engine, exhibited only in models and drawings, is employed for the same purpose as the centrifugal pump. Steam-power is not used in this case, but is obtained from the pressure of a column of water, which, acting upon a plunger, generates a reciprocating instead of rotatory motion. Engines of this description have been long employed in the mining districts of this country and the Continent. Professor Rankin states, that for the most successful application of these engines, as regards efficiency, it is necessary that the motion of the water should be slow, and as far as possible without shock. Three to six strokes per minute, or a velocity for the piston of one foot per second, is about the ordinary speed. The stroke also should be long, and therefore 'the most advantageous use to which a water-pressure engine can be put is the pumping of water, to which slow motion and a long stroke are well adapted, because they are favourable to efficiency, not only in the engine, but in the pump which it works.'

Grinding, Crushing, and Cutting Machines.—The Exhibition has been fruitful in this department of machinery, some of them being exceedingly well constructed, and entitled to every commendation for the high finish bestowed upon them. Of late years corn-mills have been greatly improved, and the system of arranging the millstones in a line along one side of the mill, and rendering the whole of the processes self-acting by an improved

system of cleaning, brushing, and separating the grain with elevators, Archimedian screw creepers, and an improved process of wire and silk dressing, give a degree of perfection to the manufacture that could not be attained when the grinding machinery was less perfect. Several small mills, chiefly on the French system of driving the stones with belts, are exhibited; and others with high-pressure horizontal engines, driving from two to four pairs of stones, are entitled to notice for convenient arrangement and the superior finish of the workmanship.

Several examples of machinery for the colonies are exhibited from Liverpool and Glasgow, and most of these are of a class calculated to meet all the requirements of complete trains of sugar-machinery; as comprised in the steam-engine, rolls for crushing the sugar-canes, evaporating-pans, and centrifugal machines. In this description of machinery there is no particular novelty or improvement, excepting only the steam-engine, which of late has undergone some change in rendering the whole apparatus more portable and convenient for exportation. In oil and powder mills the examples were not striking at the Exhibition, if we except the grinding and compressing apparatus of Messrs. Samuelson & Co., of Hull. That firm exhibited a complete set of hydraulic pumps and pipes for extracting the oil from the seed inclosed in canvas bags.* They also exhibited a pair of edge-stones in motion, which created considerable interest as a point of attraction to visitors during the exhibition.

The Machinery for the Manufacture of Textile Fabrics comprises the largest class of ingenious machinery and clever contrivances ever submitted to public inspection; and these may be divided into machinery for the manufacture of cotton, flax, and wool, including stranding and

* For a complete description of Oil Mills, *vide* 'Mills and Millwork,' part ii. second edition, page 221 *et seq.*

rope machinery of every description. Our space will prevent us from noticing in detail the numerous machines now in use in the different processes of manufacture, from the raw material to the finished article ready for the market. In cotton alone we have no less than from twelve to fifteen preparatory machines, in as many distinct processes, before the article is converted from the cotton into cloth; and these are distinguished as machines for opening, blowing, carding, drawing, slubbing, roving, spinning, winding, warping, dressing, and weaving, exclusive of other subordinate processes. In all these operations may be seen an automaton system of movements, regulated with the same precision and nicety as a timepiece. The amount of work done and of power expended in this department of manufacture alone appears almost fabulous, and great numbers of hands are employed, not as prime movers, but as 'tenters' feeding the machines—*unhappily no longer in daily use owing to the American war*—for the production of this colossal manufacture. Many of our readers may be unacquainted with the magnitude of this important branch of national industry; but we may venture roughly to state that the annual value of this manufacture is upwards of £70,000,000, and employment is given to nearly one million of persons, or, with their dependencies, upwards of two millions.

The cotton machinery is well represented in this year's Exhibition by Messrs. Platt, Hetherington, Dobson, and others; and the adaptation, style, and character of the machinery are of the first order, and do the mechanical genius of this country great credit. All the minutiæ of construction appear to be attended to, and the utmost care observed, so that all the preparatory processes are performed by the machines, with a degree of exactitude far exceeding that of the human hand. Of late years a most

ingenious machine has been introduced from Alsace, in France, as a substitute for carding. It is a combing machine, and its operations are so exact, and its work so perfect, as to enable the spinner to produce a finer description of yarn from an inferior quality of cotton. This machine is available for the finer numbers of yarn, and is one of the most important inventions since the days of Arkwright and Crompton. It has undergone great improvements since its introduction into this country, and is now extensively employed in the preparatory processes for flax and wool, as well as cotton.

The power-loom combines within itself many important improvements in twills and figure-weaving. The revolving shuttle-box, and the changes that may be effected in colour and form, cause a close run between it and the Jacquard; and many of the beautiful fabrics in cotton, wool, alpacas, and mixed goods, are woven by these looms, and that with a degree of despatch equivalent to nearly forty yards of cloth per loom per diem. To this department of machinery the contributions have been large and successful, and pattern looms from almost every district distinguished for a particular manufacture have been exhibited.

The same degree of progress is observable in flax machinery as in cotton; and the screw-gill machinery first introduced by the late Sir Peter Fairbairn is strikingly exemplified in the Exhibition. A whole train of this machinery, consisting of heckling, carding, roving, and spinning, is exhibited by different makers; and judging from the superior workmanship and adaptation of the machines to the various processes, we should infer that in flax the same progressive improvement exists as in that of cotton or any other description of manufacture. The same may be said of the long wool, alpaca, and mohair manufacture: but it is much to be regretted that samples

from the great works of Saltaire have not been exhibited. The Exhibition has not been well represented in short-wool machinery; but several specimens from Leeds and the West of England are to be seen, exhibiting improvements on the old system of manufacture. From Belgium there are, however, some very good machines, together with several ingenious contrivances for the preparatory process, and for the ultimate finish given to the cloth. In the manufacture of woollen cloth, the Belgians are not behind, if they are not in advance of the manufacturers of this country.

Locomotive Machinery and Railway Plant.—Of all the changes effected by steam, that of a locomotive travelling on a road of iron is the most wonderful, and this country has reason to be proud that it has cradled and nursed this Herculean machine from infancy to maturity. It is not the invention of one individual, but the labour of many; and none have done more for insuring its efficiency than the two Stephensons, father and son. Not that the late George Stephenson had any extraordinary inventive powers, but he possessed a keen sense of observation, and an indomitable perseverance in every pursuit in which he was engaged; and hence followed his great success as a railway engineer. It is curious to trace the early beginnings and history of this machine from the time of Trevethick and Blenkinsop (as given by Mr. Smiles in his interesting work, 'The Lives of the Engineers') to its final completion in its present high state of perfection. As a steam-engine, there is nothing new or striking in its form or construction; its power and success depend almost entirely on the boiler as a generator and a never-failing source of supply of steam. To this small vessel, 11 feet long and 3 feet 10 inches in diameter, with a square fire-box at the end, we are indebted for the almost incredible performances which

we daily witness on every line in the kingdom. Few of our readers are probably acquainted with the simple yet effective contrivances by which this comparatively small vessel exercises such enormous power over a dead weight of two hundred tons, which it hurls along on its iron course with a velocity far exceeding that of the swiftest race-horse. This is the work of a machine mounted on six wheels, and contains within itself, at a pressure of 150 lb. per square inch, a force of 7,000 tons bottled up ready for use. A tithe of that force could not be generated in the same space but for two causes; namely, the large heating surface exposed to the action of the furnace, and the blast from the cylinders into the chimney. It is to the first, as the recipient of heat, and to the second, creating a draught through the furnace, that this enormous force is due. To the philosopher and engineer these principles are familiar; but to those who have not examined the parts, and made themselves acquainted with the principles on which they are based, they must ever remain an enigma.

It will not be necessary in this place to point out and describe the uses of the different organisms of this very tractable and powerful machine; suffice it to observe that in so far as regards simplicity of design, quality of material, and sound construction, the English engineer is in advance of all his competitors; yet certainly not so far ahead but that he may be overtaken and distanced in the race, unless he maintains his position as a leader and trainer in the mechanical sciences and constructive art. It must be acknowledged, in justice to our foreign neighbours in France and Germany, that their engines are not only well made, but they combine several ingenious contrivances for the ascent of steep gradients, and the safe working of tortuous lines in mountainous districts. The only fault that can be urged against the foreign engine is

the complexity of its parts, and a want of that simplicity of form which distinguishes the English construction.

In the locomotive department there is nothing new to record, excepting that the engines and tenders, as a whole, are superior in power and construction to those which were exhibited in Hyde Park in 1851, and at Paris in 1855. We must not, however, lose sight of Giffard's injector for supplying the boiler with water; and a novel invention by Mr. Ramsbottom, the engineer and locomotive superintendent of the London and North-Western Railway, for supplying the tender with water when the engine is running. This ingenious apparatus consists of a dip-pipe or scoop attached to the bottom of the tender, with its lower end curved forwards, and dipping into the water contained in an open trough, lying longitudinally between the rails at about the rail level, so as to scoop up the water and deliver it into the tender-tank while running. The speed in practice at which water is picked up varies from a minimum of twenty-two miles per hour.

By means of this apparatus, the size and dead weight of tenders for running a given distance are reduced, as also the time required on the journey. It has been in use on the Holyhead line since October 1860, and since that time about 2,250,000 gallons have been picked up. Another trough has lately been laid down on the Liverpool and Manchester line, and a third near Wolverton—the last being intended for the use of the fast trains which run between London and Rugby, a distance of eighty-two miles, without stopping. The picking-up apparatus was illustrated in the Exhibition by a working model. An engine, similar to that exhibited, has run from Holyhead to Stafford, a distance of 131 miles, without stopping, in 144 minutes: being at the average rate of 54½ miles an hour. An engine of the same class lately brought the mail train from Holyhead to London, a

distance of 264 miles, being the greatest continuous run ever made by one engine. The average speed was 42 miles an hour.*

The Machinery of Agriculture imports a new era in the history of mechanical science, and in this uncertain and precarious climate it is a desideratum that we should have the means, not only of preparing the soil, but we should avail ourselves of every favourable opportunity for gathering in the crops, and housing them with safety in wet weather. In tracing the history of our agricultural improvements, it will be found that they originated with a few distinguished men in the south-eastern parts of Scotland, and with the father of English farming, Arthur Young, the great breeder, and the most talented of English farmers. To these men we owe the first movement in agricultural improvements, and from their time up to the present there has been steady progress. It would not be too much to say that the produce of the soil of this country has been trebled within the last century, and the quantity of land reclaimed from sterility, and the improvement of that previously cultivated, has been such as to excite the wonder of the past, and to stimulate the exertions of the present generation. Even as late as the beginning of the present century, although much had been done in draining, accompanied with the new system of rotation of crops, comparatively little had been accomplished in the shape of machinery as applied to the labours of the farm. The south of Scotland took the lead in a superior class of implements for tillage, and the thrashing-machine, driven by water and horses, was introduced about the same time by Andrew Mickle, of East Lothian; but steam as a substitute for animal power had never been thought of, and until the last ten

* *Vide* 'Practical Mechanics' Journal,' p. 272.

or fifteen years the great steam arm of science remained a listless agent, inoperative in the hands of the agriculturist.

At the present day the very reverse is the case: as steam-engines, steam-ploughs, and other steam drudges of the farm, are not only appreciated, but they testify their value by their presence at the Exhibition.

In this display we recognise one of the most imposing sights in the world's fair, and it is not too much to say that the agricultural mechanician has equally distinguished himself for solidity of construction, simplicity of details, and economy in price, with his contemporaries, the marine and locomotive engineers. The steam-ploughs of Fowler, and the engines and machinery of Ransome & Clayton, may challenge competition in any department of mechanical science, and the implements generally in this important division are exceedingly well made and admirably designed for the purposes for which they are intended.

Reaping-machines of almost every description are well represented at the Exhibition, and there appears to be no end of cultivators, grubbers, and sub-soilers, all of which are carefully designed and well made. In the construction of reaping-machines, considerable improvements have been from time to time effected by Smith, Bell, McCormack, and Crosskill; but the labours of the engineer are of little value unless supported by the agriculturist in the preparation of the land, so as to render it available for the work of the machine. To make a reaping-machine work well, *everything* must not be left to it; the farmer has his duty to perform in preparing the land as well as the machine, and that being carefully accomplished, the great problem of machine labour will soon be solved, and the farmer may then calculate with certainty upon securing his crops in the worst of seasons. In a variable

climate, such as that of England, where a whole harvest may be lost or seriously damaged unless rapidly cut and securely housed, the machine-reaper becomes invaluable, and cannot fail, when properly constructed and applied, to become the farmer's friend, and a great national benefit.

Miscellaneous Articles and Machines.—Amongst these is a splendid collection of tools of varied forms of construction; such as lathes and machines for boring, planing, grooving, and slotting, including steam-hammers, riveting, punching, and wood-cutting machines of every description, and are well entitled to consideration. They are well and ably represented by the first makers, and for these, as well as for the paper and letter-printing machine makers, too much cannot be said; the ingenuity and skill with which these valuable and important machines have been produced surpass all description.

If we examine the state of society as it now exists, in comparison with what it was nearly a century ago, and observe the amount of work then done by manual labour without the assistance of machinery and the steam-engine, it will be found that the labour of one individual in those days was not more than one hundredth part of what it is at present; and this immense increase of work does not arise from any increase in the muscular strength of man, but from his having called to his aid that all-powerful and never-failing agent, steam, and the beautiful organisms to which its power is applied.

We might instance innumerable examples by which the ingenuity of man has, by appliances and the adaptation of machinery, turned to account the natural products of the earth to supply his wants, and contribute to the social comforts of his existence. In the manufacture of cotton, one man will spin one thousand times more yarn than could have been done before the introduction of the steam-

engine and machinery; and in the manufacture of iron, the work of one individual with the aid of the rolling-mill is increased nearly in the same proportion. Other manufacturing processes have undergone the same beneficial changes, and we have reason to hope, from the exertions of an intelligent and well-conducted population, that the advantages thus gained will be preserved and increased throughout future generations.

Having thus glanced, however imperfectly, at some of the leading objects in the machinery department of the great International Exhibition recently closed, we may safely state in conclusion that more splendid and more instructive examples of the useful arts were never at any previous time brought under the inspection of the public. There is no department of practical science which has remained unrepresented, and the student, mechanic, or engineer, had only to read in his own department of study the great page of nature and art which, at this Exhibition, was laid open for his perusal. It is a great privilege for the present generation to have had before their eyes the finest specimens of the manufacturing machines in operation in their day, and in the construction of which it is their ambition to excel. This is an advantage of which few countries can boast, and it is of a character that will leave its impress upon the public mind, and will raise the thinking and industrial portion of the community of this and of all other nations much higher in the scale of civilisation.

IV.

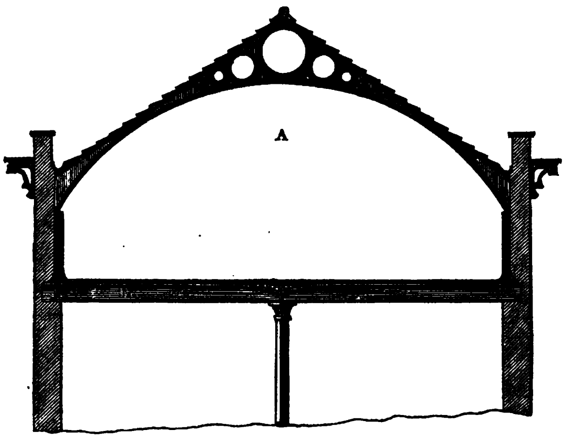
ON THE CONSTRUCTION OF IRON ROOFS.

IRON roofs date from a comparatively recent period, but the extended use of rolled iron has given a wonderful impetus to its application in the construction of roofs. Some few, indeed, were made of iron before the close of the last century; its uses, however, were very limited previously to its introduction into this city in the year 1804. During the rapid extension of the cotton manufacture, most of the fire-proof mills were covered with iron roofs of the form represented in fig. 16, and this description of roof, with its series of interior arches, was found very convenient, as it gave a spacious room in the attic story, as shown at A, fig. 16, for machinery or other purposes. Perhaps the only drawback to its employment was the expense, which amounted to nearly the same cost as an additional story.

Another form of roof was introduced by Messrs. Fairbairn & Lillie, in 1827, and has been very generally adopted since that time for large buildings, railway stations, and other structures where the span does not exceed 50 feet. It is a simple and effective structure, composed of trussed cast-iron principals, with iron rods, on which the slates are laid and fixed with iron nails or pegs. Of recent years, and since the introduction of railways, the cast iron has given place to wrought iron of the angle and T iron forms; and, considering the facility with which this material can be obtained from the rolls,

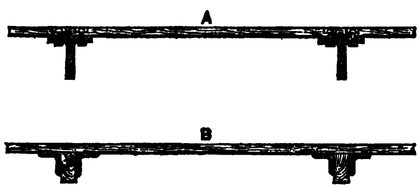
it is probably one of the simplest and most effective roofs that can be made. These are generally adopted for the principals from three to four feet asunder, covered with

FIG. 16.



thick boarding fixed to the T iron as shown at A, fig. 17, or what is more convenient is to have two angle-irons

FIG. 17.

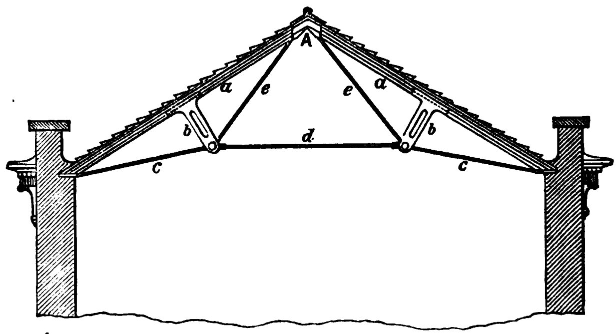


with a piece of wood bolted between them, as shown at B, and to which the boards are nailed.

Fig. 18 represents a roof of this kind, *a, a* forming the principal, and *c, c* the tie rods attached to cast-iron shoes,

which rest upon the walls on each side, and uniting to the rods *e, e* at the struts *b, b*, which rods terminate in a similar cast-iron box prepared for their reception at A. From this arrangement it will be seen that the combination of the tie rods and the struts render the structure stable as regards retaining the rafters from bending, whilst the tie rod *d* resists the tendency when loaded to thrust out the walls and keeps the principal in form.

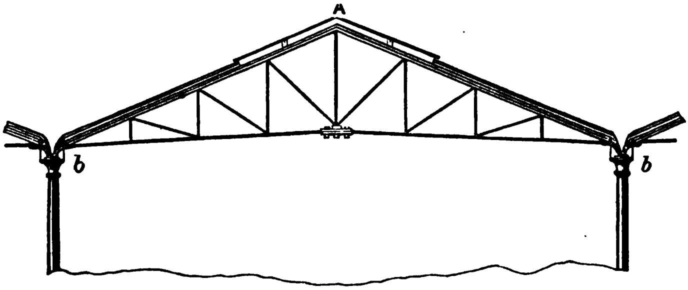
Fig. 18.



Roofs of wider span are of greater complexity, and require to be carefully constructed in order to give the necessary rigidity and retentiveness of form. Every pair of principals composing such structures should be self-supporting, that is, should have sufficient stiffness within itself to sustain a load of 40 lbs. per square foot, without yielding to pressure, or causing any thrust upon the side walls of the building. I have always found this test allows a safe margin, and, if the construction is new, in order to be on the safe side, one or two pairs of principals should be tested up to that standard. It may be necessary to give a few examples in illustration of the principles on which roofs of this kind are constructed, and also to explain by reference to drawings the general features of these light, graceful, and airy structures.

Fig. 19 is a section of one of the largest spans of the New Smithfield Market, Manchester. The space covered by this roof is 440 feet long by 244 feet wide. It is composed principally of wrought iron, and consists of two central spans of fifty feet each. The whole is supported by cast-iron gutter girders *b*, *b*, of an average length of

FIG. 19.



23 feet each, resting on columns about 25 feet high. At the apex A of each roof is a skylight 15 feet wide on each side of the ridge running the whole length of the market, and supported on louvre framing, by which ample ventilation is secured. The total area of glass is upwards of 60,000 square feet.

FIG. 20.

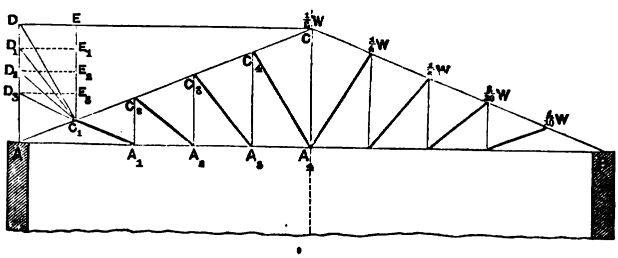


Fig. 20 represents a system of trussing very generally adopted, and roofs so constructed are known by the name of king and queen post-roofs. The number of secondary

trusses to support the rafter varies according to the span; and, in the present case, it is supported by four of these. which, according to Mr. Birckel, are AA_1C_1, AA_2C_2, AA_3C_3, AA_4C_4, and the stresses must be determined for each separately. Here the distribution of the load is as follows:— $\frac{1}{5}$ of the weight on the rafter, or $\frac{1}{10}W$, rests directly on each of the points C_1, C_2, C_3, C_4, and $\frac{1}{20}W$ at A and at C; but by means of the vertical ties connecting the trusses $\frac{1}{2}$ the weight at C_1 is transmitted to C_2; $\frac{2}{3}$ of the load at C_2 is transmitted to C_3; $\frac{3}{4}$ of the load at C_3 to C_4, and $\frac{4}{5}$ of that at C_4 to C; so that, finally, we have at C_1 $\frac{1}{10}W$; at C_2 $\frac{3}{20}W$; at C_3 $\frac{1}{5}W$; at C_4 $\frac{1}{4}W$ and at C $\frac{1}{2}W$. If the rise of the roof be made to represent $\frac{1}{4}W$, $DC=H$ will represent the pull on the tie rod, and $AC=R$ the thrust on the rafter as due to the primary truss. To determine the stress upon the component parts of each secondary truss; from the point C_1 let us draw the line C_1D parallel to the strut C_4A_4; C_1D_1 parallel to C_3A_3; C_1D_2 parallel to C_2A_2, and C_1D_3 parallel to C_1A_1. These lines will respectively represent the thrusts upon the struts to which they are parallel: $DE=H_1$ represents the pull on the tie rod, and $AC_1=R_1$ the thrust upon the rafter, as due to each secondary truss. It is worth noticing here that, in this system of trussing, the two latter stresses remain constant for each secondary truss. C_1E_3, C_1E_2, C_1E_1, respectively, represent the pull on the vertical ties A_1C_2, A_2C_3, A_3C_4; and C_1E represents one-half the pull on the king post A_4C, the pull here being double that shown by the diagram of forces, because the resultant stress from the corresponding truss on the other rafter is also thrown upon this rod. The resultant stresses, therefore, are as follows:—

PULL ON THE TIE ROD.

Between $A_3A_4 = H + H$
" $A_2A_3 = H + 2H$
" $A_1A_2 = H + 3H$
" $A\,A_1 = H + 4H_1$

THRUST ON THE RAFTER.

Between $C\ C_4 = R$
„ $C_3 C_4 = R + R_1$
„ $C_2 C_3 = R + 2 R_1$
„ $C_1 C_2 = R + 3 R_1$
„ $A\ C_1 = R + 4 R_1$

And the maximum strains are, for the pull on the tie rod, represented by $\frac{9}{10}$ its own length, and for the thrust on the rafter by $\frac{9}{5}$ its own length; but if the number of secondary trusses on each rafter were reduced to three, the maximum stresses would be as follows: viz., the thrust on the rafter represented by $\frac{7}{4}$ its own length, and the pull on the tie rod by $\frac{7}{8}$ its own length.

These strains are, however, made much more apparent by the following tables, which have been calculated for practical purposes, and which give the strain in lbs. on every part of a roof constructed on the principle shown in fig. 20. The strains, it will be observed, are computed for roofs varying in span from 20 to 100 feet.

TABLE I.

Table of Strains on King and Queen post Roofs with Horizontal Tie Beams, calculated for one foot width between the principal trusses; the total load being taken at 40 lbs. per square foot. Angle of Roofs, 26° 35′. Ten bays being formed by intersection of struts and ties.

Half span of Roof in feet.	Length of Rafter in feet.	Rise of Roof in feet.	Load on each truss for 1 foot distance apart in lbs.	Strain on Tie Rods, in lbs.		Thrust on Rafters, in lbs.		Strain on King and Queen Rods.			
				At $A_3 A_4$	At AA_1	At CC_4	At AC_1	At $A_1 C_2$	At $A_2 C_3$	At $A_3 C_4$	At $A_4 C$
10	11·2	5·	896	640	960	500	900	44	88	134	358
15	16·7	7·5	1344	960	1442	750	1350	66	132	201	537
20	22·4	10·	1792	1280	1924	1000	1800	90	180	270	720
25	28·0	12·5	2240	1602	2404	1250	2250	112	224	336	896
30	33·4	15·	2688	1920	2886	1500	2700	134	268	402	1072
40	44·8	20·	3584	2560	3848	2000	3600	178	356	534	1440
50	56·	25·	4480	3206	4810	2500	4500	224	448	672	1792

In using this table, the tabular numbers giving the strains are to be multiplied by the distance between the trusses in feet for the strain on any given roof. Thus, if the trusses are 10 feet apart, the actual strains will be ten times those given in the table, and for other distances in proportion.

The same method of calculation applies to similar roofs of six bays, and the same relation to the strains will have to be observed in multiplying by the distance between the trusses as before.

TABLE II.

Table of Strains on Roofs similar to the last, with horizontal Tie Beams, but with only six bays formed by intersection of struts and ties. Strains calculated for one foot distance between the trusses. Angle of roofs 26° 35′. Total load, 40 lbs. per square foot.

Half span of Roof in feet.	Length of Rafters in feet.	Rise of Roof in feet.	Load on each truss for each foot distance apart, lbs.	Strain on Tie Rod in lbs.		Thrust on Rafters, in lbs.		Strains on King and Queen rods. in lbs.		Thrust on Secondary Trusses in lbs.	
				Least	Greatest	Least	Greatest				
10	11·2	5·	896	598	746	500	834	74	298	168	209
15	16·7	7·5	1344	896	1118	750	1250	112	446	252	314
20	22·4	10·	1792	1196	1492	1000	1668	148	598	336	408
25	28·0	12·5	2240	1495	1865	1250	2085	186	746	420	523
30	33·4	15·	2688	1792	2236	1500	2500	224	892	500	628
40	44·8	20·	3584	2392	2984	2000	3336	296	1196	672	837
50	56·0	25·	4480	2990	3730	2500	4170	373	1490	840	1047

In this system of trussing, the tie rod is generally raised out of the horizontal line, as shown by fig. 21, and the diagram of forces, which, it may be well to state, holds good for any number of secondary trusses, undergoes a slight modification. In this case C D is to be drawn parallel to $A A_4$, and $A D = C A_4$ is to stand for $\frac{1}{4}W$; C D then will represent the pull on the tie rod, A C the thrust on the rafter, and 2 $D D_4$ the pull on the king post, arising

from the primary truss. The stresses due to the secondary trusses, as also the resultant stresses, will now be determined as previously, care being taken not to omit the quantity 2 D D_4 in computing the pull on the king post.

Fig. 21.

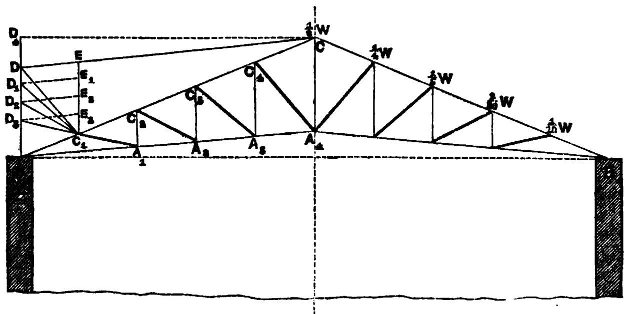
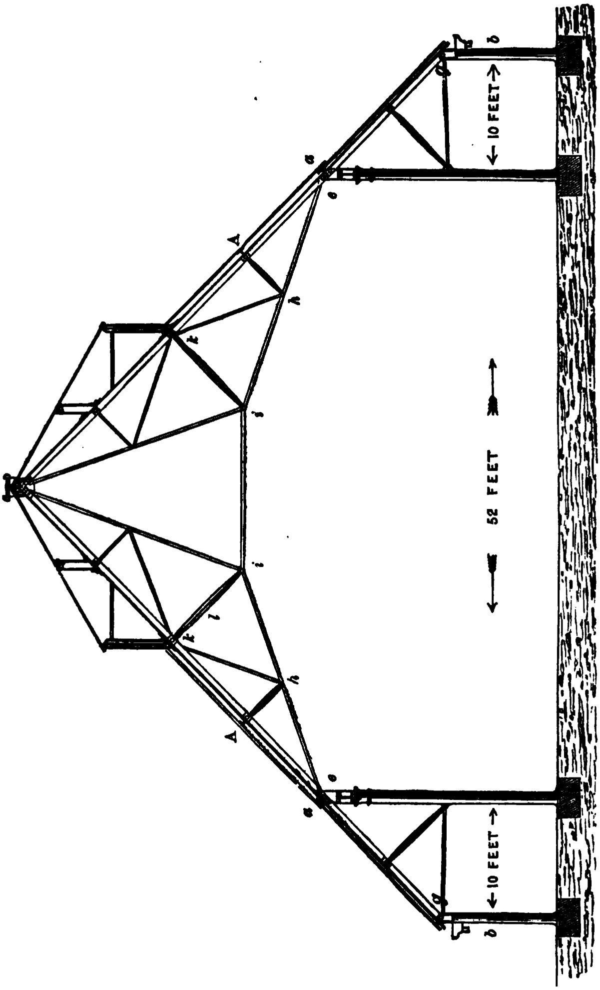


Fig. 22 is a roof and shed for the Russian Admiralty, and was, in the first instance, designed with an intended space of 10 feet between the principals. At the express desire of the Russian officials, however, this distance was increased to 20 feet, although by so doing the weight of the structure has been somewhat increased also. The whole width of the space roofed over is 72 feet, but the actual span of the principal is only 52 feet, there being a space of 10 feet on each side, covered with a lean-to roof glazed in the whole of its length, and so placed as to be continuous with the main rafter. This arrangement has been adopted in imitation of some of the sheds at Chatham Dockyard, for convenience of carrying a line of shafting on the main standard. The roof is very high pitched, being at an angle of 45°, on account of the heavy falls of snow experienced in the Russian climate; a louvre roof at a smaller angle of 30° spans about one-fourth the whole roof, the vertical sides of which are glazed to admit the light into the centre of the building; and in order to

prevent any great accumulation of snow upon it, a small platform has been provided upon the ridge to admit of a

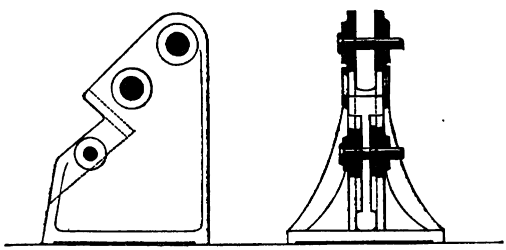
Fig. 22.



man walking along and pushing the snow down when that is required. The whole of the shed, with the exception of

the glazed portions, is covered and enclosed with corrugated galvanised iron No. 20 W G. This circumstance has enabled the constructors of the roof, without incurring any additional expense, to place the purlins immediately over the centres of resistance of the trussing, and thus the rafters are relieved from all bending stress. The thrust upon them is $25\frac{1}{2}$ tons, to resist which we have an area of $4\frac{1}{2}$ square inches, causing a stress of $5\frac{3}{4}$ tons on the square inch. The main tie rods and braces are made of flat bar iron for the sake of cheapness and expedition in the execution of the work; the lower ties are made of two bars $3\frac{1}{2} \times \frac{7}{16}$ in., and, deductions being made in the area for bolt holes, sustain a stress of $8\frac{1}{2}$ tons to the square inch; the braces are made of a single bar $3\frac{3}{4} \times \frac{1}{2}$ in., and sustain the same amount of stress; the main portion of the raised tie sustains only a stress of $4\frac{1}{2}$ tons on the square inch, and might have been made a little lighter, but for the sake of appearance. Fig. 23 is an enlarged elevation and cross section of the cast-iron brackets

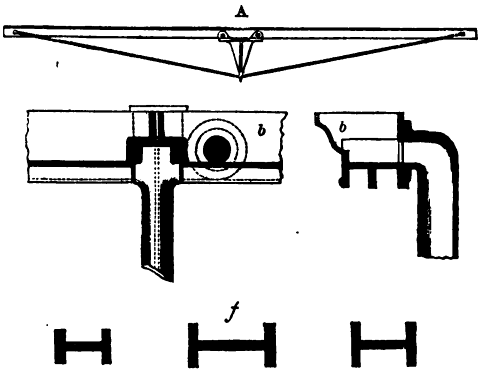
FIG. 23.



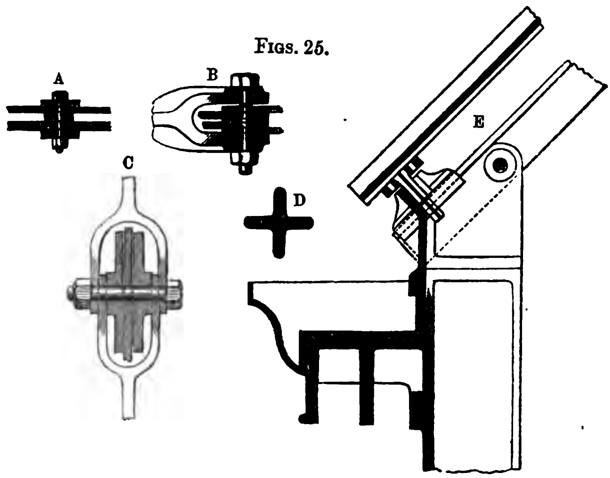
a, a, fig. 22. Fig. 24 represents the trussed purlin A, a section and cross section of the outlet-pipe *b*, fig. 22, and *f*, the beams *e e*. E, fig. 25, is an enlarged view of the portion *g* of the roof, fig. 22, showing the method of connection. The plan of the joints *h, h*, is shown at A, of the joints *i, i*, at B, of the joints *k, k*, at C. A cross section

of the strut *l*, is shown at D. The glass here, as in some of the previous examples, is carried by T iron sash bars, placed at distances of 12 inches, with the exception of

Figs. 24.



Figs. 25.

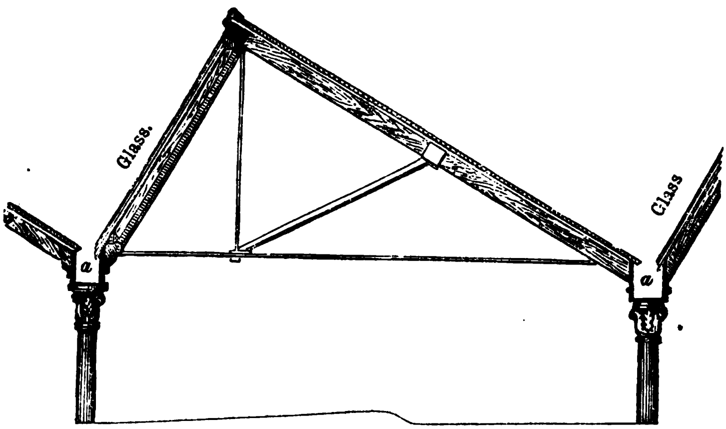


the glazed portions of the louvre roof and of the gable end, where the sashes are made of wood. The purlins are of T iron, excepting in those places where they carry

the sashes, being there made of channel iron. Owing to the great span between the principals, they are trussed, but might with safety have been a little lighter.

As an example of the construction of the roofs of weaving sheds we may instance that of Titus Salt's, of Saltaire. This shed is divided into parallelograms of 36 feet in one direction and 18 feet in the other. At

Fig. 26.



the angles of each division cast-iron columns are fixed, which support thirteen lines of cast-iron gutters marked *a*, *a*, fig. 26, and these are cast of dimensions calculated to form entablatures for the columns, and supports for the reception of the roofs which extend from east to west, in the same direction, as also the glass divisions in every compartment which face the north, and give nearly at all times of the day a steady uniformity of light. The combing-shed is of similar construction, but with this exception that it is divided into squares of 18 feet, and supported by columns, &c., in the same manner as the weaving shed.*

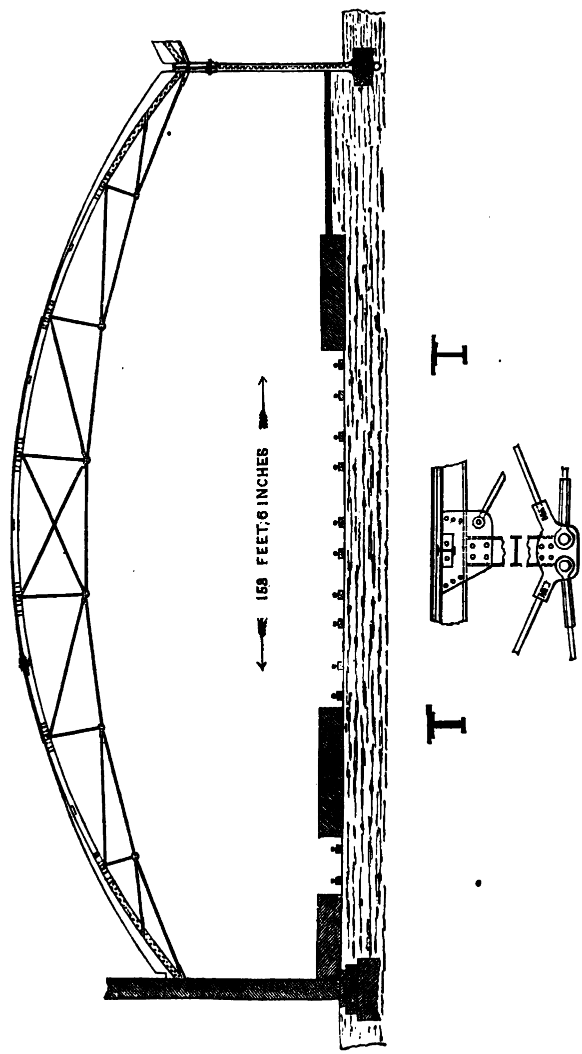
* See 'Application of Iron to Building Purposes,' 4th edit., p. 182.

The roofs of powdermills differ essentially from those already described. In the construction of powdermills it is a question of much importance to have the grinding and other processes separate from each other, as in the event of explosions in any one department it should not communicate to the others. This precaution has been considered essential in every well-regulated powdermill, and to attain that object, most establishments have their mills at 100 to 150 yards distant from each other. When this arrangement is found inconvenient, and the mills have to be nearer together, they are then separated by butts or mounds of earth, at a considerable height, and tapering to the top like the roof of a house. The more recent erections are, however, different since the introduction of the cast-iron runners, as will be seen in the arrangement, on referring to 'Mills and Millwork,' vol. ii. page 247.

In illustration of circular iron roofs, I have selected amongst others that over the Lime Street Station, Liverpool, constructed by Mr. Richard Turner, of the Hammersmith Iron Works, Dublin. Its extreme length is 374 feet, and breadth 153 feet 6 inches. This roof, fig. 27, consists of a series of segmental principals or girders, fixed at intervals of 21 feet 6 inches from centre to centre. The principals are trussed vertically by radiating struts, made to act by straining the tie rods and diagonal braces; they are trussed laterally by purlins, placed over the radiating struts and intermediately between them; also by diagonal bracing, extending from the bottom of the radiating struts to the top of the corresponding ones in the adjoining principals.

Each principal is composed of a wrought-iron deck beam, nine inches in depth, with a plate 10 inches wide and ½ inch thick riveted upon the top. The curved rib is formed of seven pieces, connected with each other at the points where the radiating struts are attached by

Fig. 27.



means of plates riveted on both sides. There are six radiating struts in each rib, varying in length from six to twelve feet; they are seven inches in depth, and are attached to the tie rods by wrought-iron link plates. The sectional area of the tie rods is $6\frac{1}{2}$ inches.

The diagonal braces hold the struts tight up against the principals, and assist the tie rods in giving the required rigidity to the principals; they are formed of round bar iron $1\frac{3}{8}$ inches in diameter. The ends or feet of the principals are fixed in chairs of cast iron; those on one side resting upon a solid plate, and the others upon rollers, which have the power of traversing a space of three inches; also upon a metal plate, so as to admit of any contraction or expansion of the rib, though up to the present time no motion has been observed. The roof is covered with galvanised corrugated wrought-iron plates, and with rough plate glass.

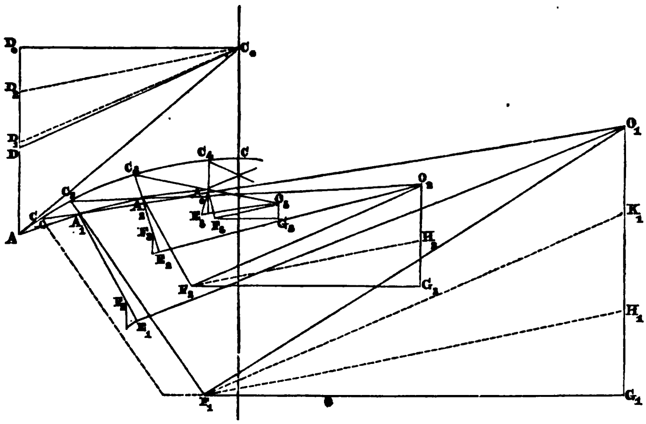
The cost of this roof was 15,000*l.*, and the time occupied in its erection was about ten months.

The superiority of a roof of this kind over the ordinary slated roofs in small spans is at once evident; not only is the space occupied by, and the intermediate columns or supports saved—thereby removing every objection to the use of sidings—but a large open space and clear ventilation is afforded for the convenience of passengers and traffic. Besides, the iron roof is much more durable, and is not subject to decay to the same extent as those composed of wood.

It will be seen, by reference to fig. 27, that the depth of the girder diminishes from the centre in the direction of the supports, until the compression and tension flanges meet at each of the extremities. Mr. Birckel observes, 'that but for this latter feature in its construction it would be like an ordinary lattice girder, with vertical struts and ties sloping from the bottom of one strut to

the top of the following ones in the direction of the supports; the fact of the two flanges meeting, however, alters the case materially, inasmuch as it compels the last sloping rod or tie, as Mr. Turner would have it, to fall upon the compression flange itself for its support; and when we remember that the strains upon those ties accumulate from the centre of the girder where they are smallest towards the ends where they reach their maximum, if we construct the diagrams of stresses on

FIG. 28.



this hypothesis, as illustrated by fig. 28, and on the assumed load of 40 lbs. per square foot, we find that the last sloping rod, if it acts as a tie, exerts a component transverse strain upon the rafter or compression flange equal to about 35 tons at a distance of 11 feet from the wall or column. As the actual direction of that supposed pull is from the wall or columns, and as the principal rests only loosely upon them, we do not see on what principle of dynamics or of statics it is not pulled away from its supports, and precipitated into the area

below, for hitherto we have been taught, and we have believed, that, wherever there is a pressure not balanced, there must be motion in the direction of that pressure, and in the case under consideration, if there is a pull upon the said sloping rod, it cannot be neutralised by the reaction of the wall, for the rafter is the only medium which could connect it with the wall. It is not supposed to be neutralised by the tension flange or tie rod, for this could only be effected by a compression strain on the tie rod; and to suppose this would be looked upon by the designer of the roof himself as an absurdity. The only resistance which we can perceive is that offered by the rafter and tie rod to bending and doubling up in the centre: a resistance which, considering their dimensions, would be of little avail against a component horizontal pull of some 160 tons, with a leverage of 20 feet; this supposed pull, therefore, could only bring about a dynamical equilibrium, the effect of which must be to bring down the roof.

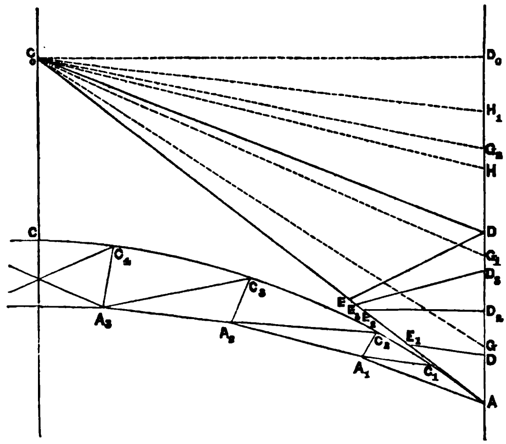
'We think, however, that it will not be difficult to prove that those supposed sloping ties do not act as ties at all, but act as struts; and that the supposed radiating struts act as ties. To effect this, we will, for an instant, suppose the principal to be without any weight of its own, and free from all external load; in fact, we will suppose it a linear structure capable of resisting any pressure we may choose to apply. At the point C_1, &c., fig. 27 or 28, we will now apply certain pressures, which, to simplify the case, we will suppose to be normal to the curve of the rafter, and of equal intensity on both sides. It is evident that these pressures will produce compression on the portion $A\,C_1$ of the rafter, and on the sloping rods $A_1\,C_1$, which compression strains are balanced by a tension strain on the parts $A\,A_1$ of the tie rod; the radial components of the strains on $A_1\,C_1$ are carried by means of the rods $A_1\,C_2$

to the points C_2, where they produce results similar to those produced by the pressures at C_1, namely, compression on the part $A\ C_2$ of the rafter, and on the rods $C_2\ A_2$, which are again balanced by a tension strain on the portions $A_1 A_2$ of the tie rod. Similar strains are produced upon the successive trusses until the summit of the roof is reached, the several strains accumulating progressively upon the rafter and the tie rods as we approach the extremities of the principal. If now we apply certain pressures at each of the centres of resistance C_2, C_3, C_4, these respectively will add themselves to the pressures transmitted from each preceding centre of resistance to the radial rods by means of the sloping rods, and the system of trussing thus naturally reduces itself into a series of radial or *quasi*-vertical ties connected by means of sloping struts, or king and queen post system of trussing.

'To the analysis which led to the above conclusion, and to the objection which no doubt will be raised by the more superficial enquirer, that, if the ties of the Lime Street roofs are struts in reality, the roof could not have stood the test of time, we shall give the ready answer, that the fact of the roof having stood this test only proves that, up to the present time, those struts have been able to do their work of resistance, and that the rafter itself, being a strong beam, required little trussing to enable it to do its work. Indeed, if we construct the diagram of stresses, as illustrated by fig. 29, on the hypothesis of the principal being a polygonal frame trussed on the system of the king post roof, with an assumed load of 40 lbs. per square foot, we find that the stress upon the rafter is a little more than 4 tons per square inch at the foot, and about 8 tons in the centre of the bay $C_3\,C_4$; the maximum stress on the sloping struts is $6\frac{1}{2}$ tons, and that on the main tie rods about $9\frac{1}{2}$ tons per square inch, which figures are a

clear proof of the correctness of the remarks we have just made. This roof, therefore, if modified in the manner we have suggested, will at all times be an elegant example to imitate; and though we have referred to it as

Fig. 29.

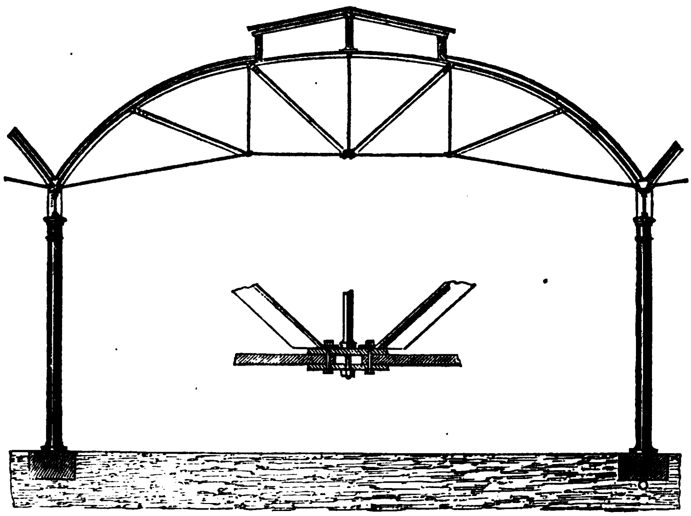


a theoretical blunder (a blunder which will be readily excused when it is remembered that at the time of its construction the theory of structures had not been rendered so easily accessible as it is now, with the help of such works as those of Rankine & Moseley), yet it is an example of iron roof construction well worthy of recording, because it represents a great stride in advance of what had previously been effected in roof construction, and must be looked upon as a bold and practically successful conception.

'Mr. Fairbairn, who was one of the parties consulted about the practicability of Mr. Turner's design, and whose opinion at the time was in favour of it, seems to have given the subject on which we are engaged his early

attention, and, with his habitual sagacity, appears to have arrived at a correct comprehension of it; for in 1857 he caused the boiler-yard now belonging to The Fairbairn Engineering Company (Limited) to be covered in with

FIG. 30.

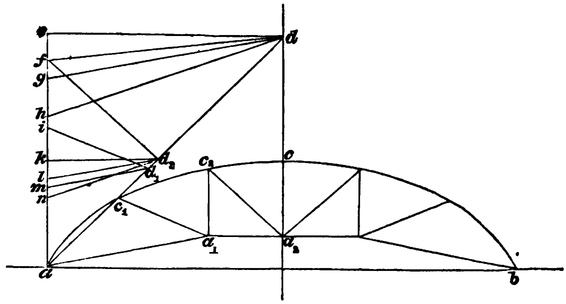


an arched roof, illustrated by fig. 30, consisting of two spans of 50 feet, with principals trussed on the system according to which, in the roofs previously analysed, we have demonstrated the reactions described to take place.

If now we construct the diagram of stresses, fig. 31, with a due regard to this particular feature of the problem, that the stress upon any portion of the polygon is represented, both in the primary and secondary trusses, by a line drawn parallel to that portion of the polygon, from the point of intersection of the extreme lines closing the diagram of the particular truss of which that portion of

the polygon forms part, we find that the rafter which is made of T iron $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{3}{8}$ in. sustains a stress of about six tons to the square inch, and is so small because the purlins have been placed so close to the second centres of resistance as to render the bending stress almost *nil*; the tie rod is made of $1\frac{1}{4}$-inch round iron, and sustains a pull of $5\frac{1}{3}$ tons per square inch; the stress on

FIG. 31.

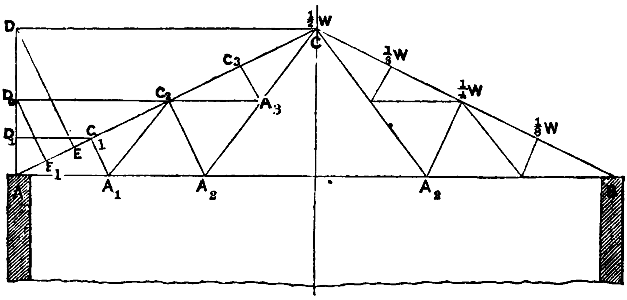


the struts, also, of the upper and lower secondary trusses is about 1 ton per square inch; the struts are made of T iron respectively $3\frac{1}{2} \times 3 \times \frac{5}{16}$ in. and $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$ in. in section. The roof is covered with corrugated iron; the principals, which are 11 feet apart, are carried by strong wrought-iron beams, which rest upon the end walls of the building, and between those on two strong cast-iron columns 18 inches in diameter, thus causing as little obstruction as possible on the floor below. The shop receives the light from a louvre roof, glazed in the whole of its width of about 16 feet, and by means of which ample provision is made for ventilation. On the whole, therefore, this roof is very well proportioned, and unites with lightness a cheap and airy construction.

'We do not wish to insist that this is the only way to

truss an arched principal correctly, for it might be trussed with theoretical propriety according to fig. 32—a form of roof peculiar to iron constructions—but we think the

FIG. 32.



king-post system has a claim to preference, because, on the one hand, it seems to us the more elegant of the two, and because, also, the thrust on the upper portion of the rafter, as we have seen, is considerably less with this system than the other, a circumstance which here is of much importance, because the almost horizontal position of that portion of the rafter causes the bending stress to be considerably larger for the same vertical load than it is at the foot of the rafter.

'In a roof trussed as shown in fig. 32, the stresses sustained by the component parts of each individual truss must be determined as if the truss was an independent structure: and to be able to do that we must see how the load is distributed upon the points A, C_1, C_2, C_3 C, which will be arrived at in the following manner: $\frac{1}{2}$W being equally distributed on each rafter, the load directly supported at the points C_1, C_2, C_3 is $\frac{1}{8}$W, and the load at each point A and B is $\frac{1}{16}$W; but the minor secondary trusses, through their tension rods, exert a pressure of $\frac{1}{8}$W, at the point C_2, and of $\frac{1}{16}$W at each of the points

A and B; the major secondary truss exerts a pressure of $\frac{1}{8}$W at each of the points A and B also, so that the final distribution of the load is, at C, $\frac{1}{2}$W, at each of the points A, B, and C_2 $\frac{1}{4}$W, and at the points C_3 $\frac{1}{8}$W.

'Let A D again represent $\frac{1}{4}$W, then DC = H will represent the stress on the horizontal rod arising from the primary truss; $D_2\ C_2 = H_2$ the stress on the ties of the major secondary truss, and $D_1\ C_1 = H_1$, the stress on the tie rods of the minor secondary trusses. The thrust on the rafter arising from the primary truss is represented by its own length AC = R; that on the lower half of the rafter due to the major secondary truss is represented by $AC_2 = R_1$; and on the upper half by $EC_2 = R_2$, the difference here arising from the component along the rafter of the weight applied at the points C_2; the stress on the lower half of each portion of the rafter forming part of the minor secondary trusses and arising from the same is $AC_2 = R_3$, and on the upper halves $C_1\ E_1 = R_4$. The resultant stresses on the various parts of the frames therefore will be

'Pull on the horizontal Tie Rod

$$\begin{aligned} \text{Between } A\ A_1 &= H + H_2 + H_1 \\ A_1\ A_2 &= H_1 + H_2 \\ A_2\ A_2 &= H \end{aligned}$$

'Thrust on the rafters

$$\begin{aligned} \text{Between } AC_1 &= R + R_1 + R_3 \\ C_1\ C_2 &= R + R_1 + R_4 \\ C_2\ C_3 &= R + R_2 + R_3 \\ C_3\ C &= R + R_2 + R_4 \end{aligned}$$

'The thrust on the struts $C_2\ A_2$ is represented by DE, and that on the struts $C_1\ A_1$ and $C_3\ A_3$ by $D_2\ E_1$.

'As the rafters are generally of uniform strength throughout their length, it will be sufficient to define the maximum thrust upon them, and it will be sufficient also to define the minimum and the maximum pull on the tie rod, and the maximum pull on the braces. A careful inves-

tigation of the diagram will show that in the case of a principal, trussed in the manner illustrated by fig. 32, if the rise of the roof be made to represent one-fourth the load on one principal, the maximum thrust on the rafter is represented by $\frac{7}{4}$ its own length; the minimum pull on the tie rod by $\frac{1}{2}$; and the maximum pull by $\frac{7}{8}$ its own length; the maximum pull on the braces is represented by $\frac{3}{8}$ the length of the tie rod. Should the minor secondary trusses be left out, the maximum thrust on the rafter will be represented by $\frac{6}{4}$ its own length; the maximum pull on the tie rod by $\frac{3}{4}$ its own length; and the maximum pull on the braces by $\frac{1}{4}$ the length of the tie rod.*

* As an illustration of the application of the foregoing, Mr. Birckel gives the following example: To determine the stresses on the various parts of a roof supposed to have a span of 50 feet, with a rise of 10 feet, the principal being 15 feet apart, and trussed according to the method shown in fig. 32. If we assume the load to be 40 lbs. per square foot, we shall have $\frac{1}{4}W = 3{\cdot}6$ tons, and each lineal foot will represent a pressure of 0·36 ton. The minimum pull on the tie rod will be

$$H = 0{\cdot}36 \text{ ton} + \frac{50}{2} = 9 \text{ tons.}$$

The maximum pull:—

$$H + H_2 + H_1 = 0{\cdot}36 \text{ ton} \times 50 \times \tfrac{7}{8} = 15\tfrac{3}{4} \text{ tons.}$$

The maximum pull on the braces:—

$$H_2 + H_1 = 0{\cdot}36 \text{ ton} \times 50 \times \tfrac{3}{8} = 6\tfrac{3}{4} \text{ tons.}$$

And the pull on the ties of the minor trusses:—

$$H_1 = 0{\cdot}36 \text{ ton} \times 50 \times \tfrac{1}{8} = 2\tfrac{1}{4} \text{ tons,}$$

which, for a unit stress of 5 tons per square inch of section, would give the following scantlings:—

For the middle portion of the tie rod:—

$$\tfrac{9}{5} = 1{\cdot}8 \text{ square ins.} = 1\tfrac{1}{2} \text{ inch diam. rod.}$$

For the ends:—

$$\frac{15{\cdot}75}{5} = 3{\cdot}15 \text{ sq. ins.} = 2 \text{ inch rod.}$$

For the braces:—

$$\frac{6{\cdot}75}{5} = 1{\cdot}35 \text{ sq. ins.} = 1\tfrac{5}{16} \text{ inch rod.}$$

'Very often, however, the tie rod is raised above the horizontal, and then the diagram of forces assumes a somewhat altered shape. Fig. 33 is an illustration of this case, and the distribution of the load being as pre-

And for the small ties:—

$$\frac{2 \cdot 25}{5} = 0 \cdot 45 \text{ sq. in.} = \tfrac{3}{4} \text{ inch rod.}$$

The length of the rafter is 27 feet, and the maximum thrust upon it will be:—

$$R + R_1 + R_3 = 0 \cdot 36 \text{ ton} \times 25 \times \tfrac{7}{4} = 17 \text{ tons.}$$

which, for a load of 5 tons to the square inch, would give an area of $3\frac{1}{2}$ square inches. Here, however, we must remember that the rafter is not only a strut but that it is also a beam subject to deflection by a bending moment, whose value, in the present instance, is

$$M = \tfrac{1}{64} \times 7 \cdot 2 \text{ tons} \times 25 \text{ feet} \times 12 \text{ inches,}$$

where the factor $\frac{1}{64}$ arises from the fact of the rafter being a continuous beam supported on three points, and whose ends cannot take any deflection. Under these circumstances the rafter should be made subject to the condition expressed by the following formula:—

$$S = \frac{R + R_1 + R_3}{A} + \frac{M d_1}{I}, \tag{1}$$

where S stands for the unit strain, A the transverse area of the rafter, I the moment of inertia of the cross section, and d_1 the distance of the fibre farthest removed from the centre of gravity of that transverse section. Now rafters are generally made of two angle irons, bolted together back to back, or of T iron, and for either of these sections we can write, with sufficient accuracy for all practical purposes,

$$\frac{I}{d} = \frac{1}{4 \cdot 5} A d,$$

where d stands for the whole depth of the L or T iron.

For the case under consideration, therefore, formula (1) would read thus:—

$$S = 5 \text{ tons} = \frac{17 \text{ tons}}{A} + \frac{7 \cdot 2 \text{ tons} \times 25 \text{ feet} \times 12 \text{ in.} \times 4 \cdot 5}{64 \, A d}, \tag{2}$$

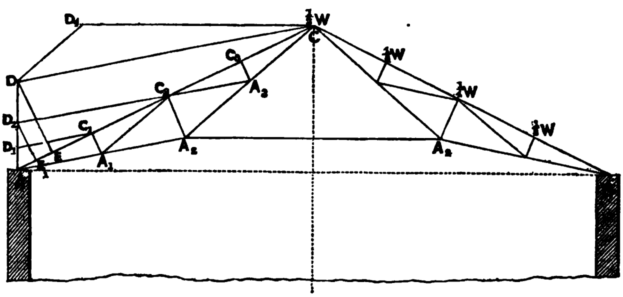
and assuming d at $5\frac{1}{2}$ inches, would give for the value of A:—

$$A = \frac{17}{5} + \frac{7 \cdot 2 \text{ tons} \times 25 \text{ feet} \times 12 \text{ inches} \times 4 \cdot 5}{64 \times 5 \times 5 \cdot 5} = 8\tfrac{1}{2} \text{ sq. inches,}$$

equivalent to two angle irons bolted back to back, each $5\frac{1}{2}$ ins. $\times$ $2\frac{1}{2}$ ins. $\times$ $\frac{9}{16}$ in. or a T iron, $4\frac{3}{8} \times 5\frac{1}{2} \times \frac{7}{8}$.

viously, if from the point C we draw CD parallel to $A A_2$, D A will stand for $\frac{1}{4}$ W; C D will represent the pull on the tie $A A_2$; $C D_4$—which is horizontal—will represent the pull on the tie $A_2 A_2$; $D D_4$, parallel to the brace $C A_2$, will represent the pull on the same, and A C the thrust on the rafter; all these being due to the primary truss only.

Fig. 33.



The stresses arising from the secondary trusses will be determined as previously, by drawing C_2 D_2 and C_1 D_1 parallel to $A A_2$; and D E, D_2 E_1, perpendicular to the rafter. The resultant stresses are to be computed as before, care being taken not to omit the additional stress DD_4 on the braces.'

The following table of strains on the component parts of roofs similar to that shown at fig. 32, and of spans varying from 20 to 100 feet, have been calculated for practical purposes. In using this table it is to be remembered that the strains on corresponding parts of the primary, secondary, and tertiary trusses are the same, and where the strains from two or more trusses come upon the same member, the resultant strain is the sum of the strains due to the separate trusses. If the distance between the trusses is ten feet, the strains will be ten times as great

as those given in the table and similarly for other proportions.

TABLE III.

STRAINS ON COMPONENTS OF ROOFS SIMILAR TO FIG. 32, FOR EACH FOOT DISTANCE BETWEEN TRUSSES. THE TOTAL LOAD BEING TAKEN AT 40 LBS. PER SQUARE FOOT. ANGLE OF ROOF 26° 35′.

Half Span, in feet.	Length of Rafter, in feet	Rise of Roof, in feet.	Total Load on Truss, in lbs.	Minimum Strain on Tie Rod, $A_2 A_2$.	Maximum Strain on Tie Rod, $A A_1$.	Thrust on rafter Minimum	Thrust on rafter Maximum	Thrust on Brace, $C_2 A_2$.	Thrust on Brace, $C_1 A_1$.	Strain on Tie, $A_2 A_3$.	Strain on $C A_3$.	Strain on $A_1 C_2$.
10	11·2	5·	896	448	785	732	882	202	101	224	336	112
15	16·7	7·5	1336	672	1177	1098	1323	303	151	336	504	168
20	22·4	10·	1792	896	1570	1464	1764	404	202	448	672	224
25	28·0	12·5	2240	1120	1960	1830	2205	505	253	560	840	280
30	33·4	15·	2672	1344	2355	2196	2646	606	303	672	1008	336
40	44·6	20·	3584	1792	3140	2928	3528	808	404	896	1344	448
50	56·0	25·	4480	2240	3925	3660	4410	1010	505	1120	1680	560

It will be noticed that in roofs of this description the strains are calculated on the same principle as those in Tables I. and II.

PART II.

CONSTRUCTION OF IRON ROOFS—*continued.*

Circular Roofs.

ANOTHER form of roof in which the principle of the arch is substituted for that of the truss, has recently been adopted with signal success. It is chiefly applied in cases where wide spans are required, such as railway stations, public markets, &c., where the intervention of columns is objectionable. It is, however, not so well adapted for the top of lofty buildings, where no provision can be made for any great amount of horizontal thrust. Where this is required the arch should in all cases be semicircular, and the peculiar properties of iron offer the greatest facilities for construction, which can be obtained by giving the ribs a depth sufficient to bring into play the forces of tension and compression on the principle of the girder.

Roofs of this description have been introduced at the Crystal Palace, Sydenham, in place of the laminated wooden arched ribs of the transept of the Great Exhibition of 1851. At Sydenham the arched roofs are 120 feet high, and 72 feet span, consisting of principals resting on double columns alternately 24 and 72 feet apart.

These principals are semicircular lattice girders of a uniform depth of 8 feet, having an inner and outer flange with the usual diagonal and radial struts and ties. At the Paris Exposition similar roofs were employed, the larger arch having a span of 157 feet in the clear, flanked by two parallel roofs each of 74 feet span. The iron principals or curved ribs, 26 feet apart, consisted of two consecutive arcs, 6½ feet asunder, forming top and bottom flanges, constructed of angle and plate-iron riveted together, as shown in fig. 34. These inner and outer arches

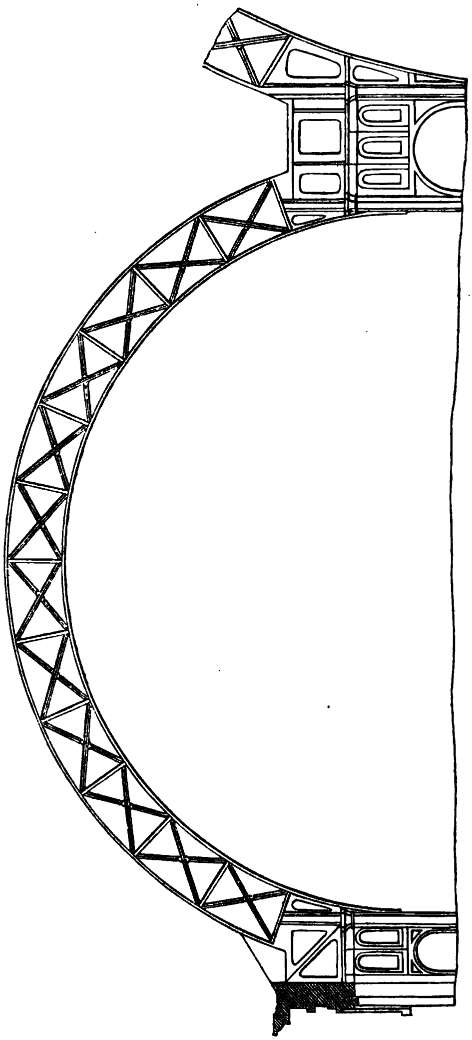


Fig. 34.

TRANSVERSE SECTION OF PARIS EXHIBITION ROOF, 1855.

are connected at distances of 8 or 9 feet by radial struts and crossed diagonals formed of T iron bolted back to back thus, ╪ all the junctions being made with rectangular lap plates. The principals are connected together at distances of 9 feet by wrought-iron purlins crossing the principals at planes radial to the curves and connected to them by quadrant pieces which, taken altogether, produces a light airy effect.

The main arched roof of the Dublin Exhibition Palace and Winter Garden, of which fig. 35 is a cross section, and fig. 36 a sectional elevation, is a very neat roof of this description. It is thus described by Mr. Carl Wessely, in a paper read before the Society of Engineers. The outline of the arched rib principal is semicircular, the radius of the intrados being 20 feet $6\frac{1}{2}$ inches, and the extrados 28 feet $1\frac{1}{2}$ inches. The rib is thus at its crown 1 foot 6 inches, and at its springing 2 feet 8 inches deep. It consists of a bottom and top flange, each of 2 L irons, $3\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{3}{8}$ in. throughout its length, connected together by diagonal bars. The four diagonals next to the crown of the rib are $2\frac{1}{2}$ in. $\times$ $\frac{7}{16}$ in., the next three are $2\frac{3}{4}$ in. $\times$ $\frac{1}{2}$ in., then follow three of 3 in. $\times$ $\frac{1}{2}$ in., and the last three are $3\frac{1}{4}$ in. $\times$ $\frac{9}{16}$ in., the rivets for connecting the diagonals to the flanges being $\frac{3}{4}$, $\frac{7}{8}$, and 1 inch in diameter, according to the strength of the diagonals. At their intersections the diagonals are connected by $\frac{3}{4}$-inch rivets. At each point where the dimensions of the diagonals vary, the purlins are fixed. There are, therefore, three purlins on each side, exclusive of the ridge purlin at the top. The purlins are of cast-iron, and their construction is well adapted for securing water-tight joints, where the covering is fixed to them. They are cast in lengths of 16 feet 10 inches, $9\frac{3}{4}$ inches in height, and $\frac{3}{8}$ inch thick, the bottom flange being $\frac{1}{2}$ inch thick. The web of the purlins is ornamentally perforated, the perforations being glazed,

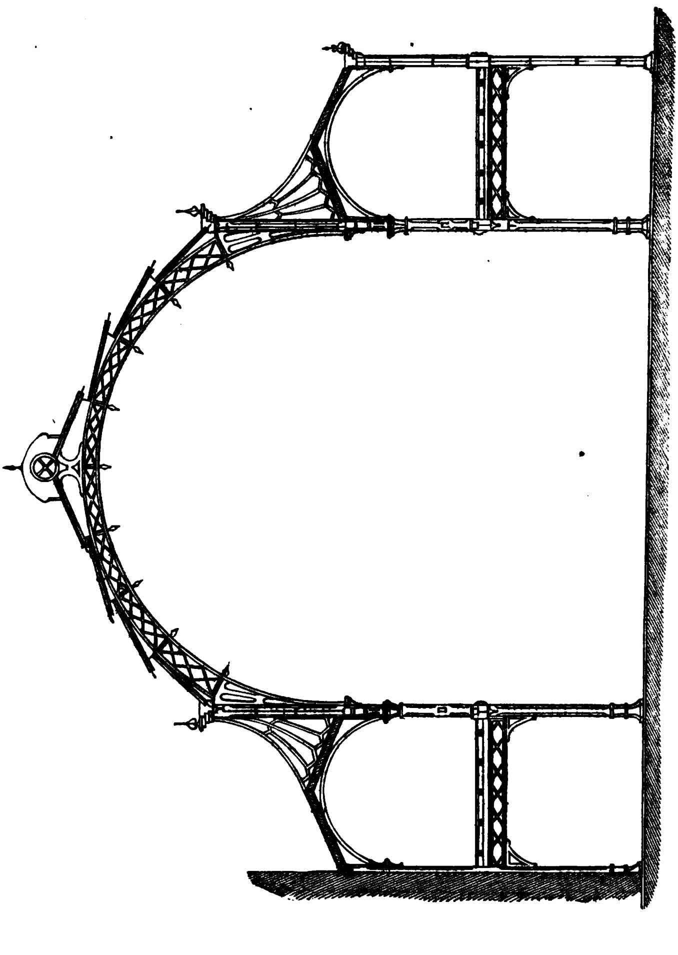


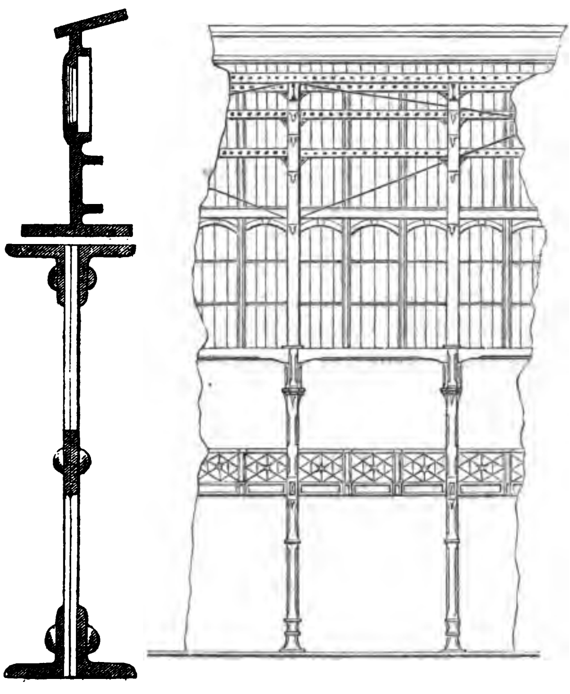
FIG. 35.

TRANSVERSE SECTION OF DUBLIN EXHIBITION ROOF, 1865.

and the joints of the purlins chipped. For connecting the purlin firmly to the rib, and to give it a certain amount of lateral stiffness, two ornamental brackets are fixed by four bolts, 1 inch diameter, to the rib, so that one end appears to support the purlin to which it is well bolted,

FIG. 36.

CROSS SECTION.



and the part fixed to the rib being half an inch in thickness acts as a stiff strut.

Under each of these brackets of $\frac{3}{8}$-inch metal, an ornamental finial is fixed to the soffit of the rib, on which a 7 ft. × $\frac{7}{8}$-in. board is fastened to cover the open space

between L irons. The two upper bolts of those connecting brackets to ribs serve for fixing the wind ties, the ends of which are flattened down in the usual way, and have right and left-hand screws for adjustment.

In addition to the Dublin Exhibition roof, Mr. Carl Wessely selected the arched roof over the Derby Market, figs. 37 and 38, for illustration. It is 86 feet 6 inches span, of the semicircular form, and the principals consist of wrought-iron arched ribs, the inner and outer curves being true circles struck from the same centre, with radii of 43 feet 9 inches, and 41 feet 5 inches respectively, the springing of ribs being 7 feet 6 inches above centre. The height of rib at crown is 62 feet 10 inches above the floor level. The wrought-iron rib is of the same depth throughout, and consists of $\frac{5}{16}$-inch web, and top and bottom flanges, each of two L irons $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{16}$ in.

At every alternate supporting place of the purlins the web is joined by means of a joint plate 1 foot 9 in. $\times$ $10\frac{1}{2}$ in., and $\frac{1}{2}$ inch thick, which plate is also riveted on to the web at the other purlins, as a strengthening plate. Angle-irons extend always over two lengths of web. The web is ornamented in an original way. A neat design of holes is punched out of the solid plate, leaving the material intact, where it acts in a similar manner to diagonals. As holes show much better than mere lines or raised ornaments, the effect is much more powerful; besides, it seems the only right way to ornament a plate girder, because the main construction lines, adapted to certain scientific laws, are not only left intact, but even brought out to a greater extent. Ornamentation by casing, and ornaments stuck on, may be sometimes really required, but if the real working structure can be made in itself good looking, its merit is by far greater. These holes (about six inches in diameter, the larger ones) were punched out by a simple screw press, with long levers

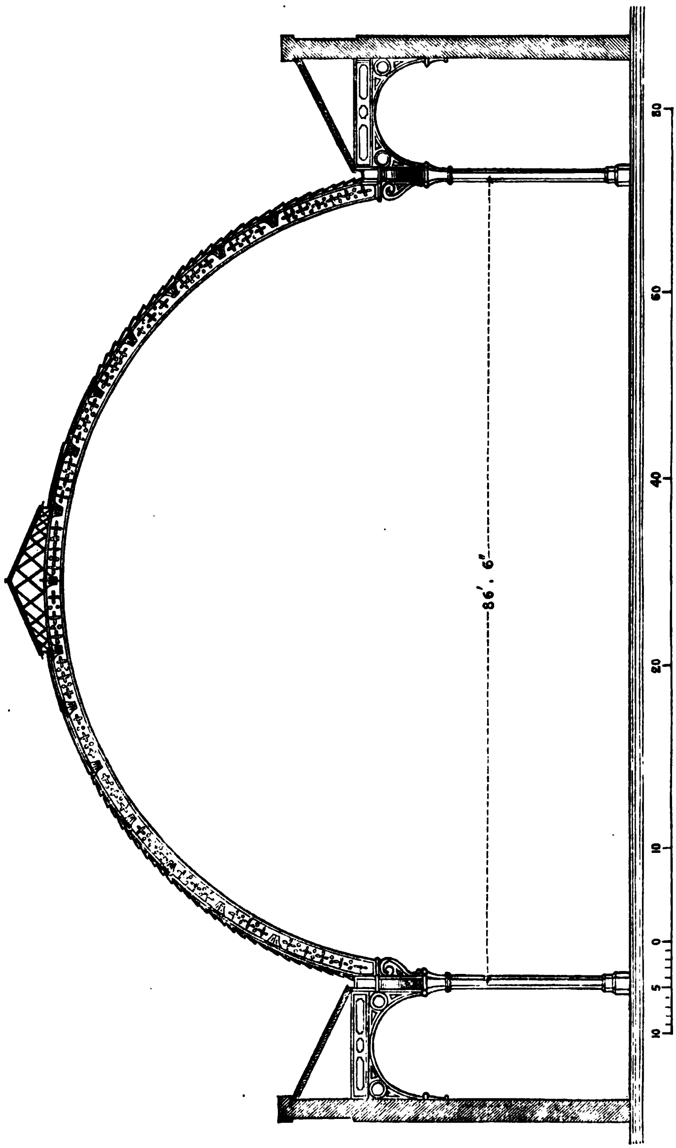


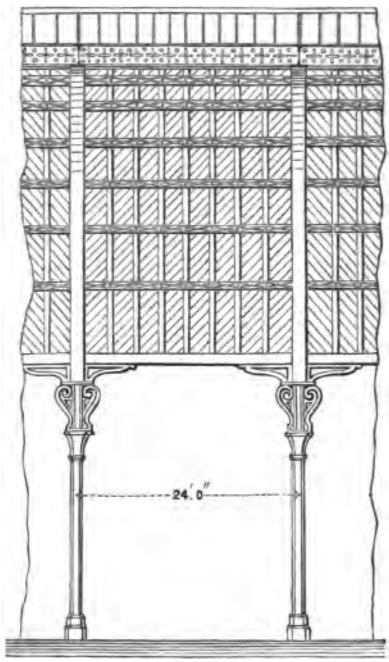
Fig. 37.

TRANSVERSE SECTION OF DERBY MARKET ROOF.

and heavy weights attached to them. When brought once into the swing, the mere momentum suffices to drive the punch through the plate, which is $\frac{5}{16}$ inch thick. The base of rib is horizontal, 2 feet long, while the top flange is 2 feet 5 inches above, carried vertically down. It is fixed by eight 1-inch bolts, on each side of the web, to

FIG. 38.

LONGITUDINAL SECTION.



the supporting cast-iron column, the angle irons of the bottom flange being carried round horizontally for that purpose. Riveting is done throughout with $\frac{3}{4}$-inch rivets, about 4 inch pitch. A board $8\frac{3}{4}$ inches wide, by 1 inch, is fixed to soffit of rib, for mere appearance. The

rib carries wrought-iron lattice purlins, at intervals of 6 feet 9 inches. On each side of such purlin, a cast-iron strut is fixed to rib and purlin by six $\frac{3}{4}$-inch bolts. By this connection, the projecting of the purlins beyond the ribs is prevented.

The purlins, which are 23 feet 10 inches long, and 1 foot 6 inches deep, are radial, and are connected to the main ribs by means of the cast-iron end struts of $\frac{3}{8}$-inch metal, by two $\frac{3}{4}$-inch bolts. They consist of a simple truss, the top and bottom flange of which are each formed by two L irons $3 \times 3 \times \frac{3}{8}$ inch. The top flange is also connected by two $\frac{3}{4}$-inch bolts to top flange of main rib. Cast-iron struts, 3 feet pitch, and flat bar diagonal bracing, $2\frac{1}{2}$ inches wide, increasing from $\frac{1}{4}$-inch to $\frac{3}{8}$-inch, and $1\frac{1}{2}$ inches in thickness, connect the flanges of the truss by $\frac{3}{4}$-inch bolts serving as pins for diagonals. Wooden diagonals are also used for giving the appearance of a complete diagonal truss. The purlins support at each strut a wooden rafter 6 in. $\times \frac{3}{4}$ in. Each alternate strut is so enlarged as to form brackets connected to the wood rafters by $\frac{5}{8}$-inch bolts, which are employed to keep the purlins in their radiating position. The other struts are brought out at the top to mere lugs fixed to rafter by $\frac{3}{8}$-inch coach screws.

On the top of the main ribs a piece of wood $5\frac{1}{2}$ in. $\times$ 3 in. is fixed for nailing the 1-inch boarding thereto.

The 1-inch boarding is covered by Italian zinc near the crown, and at the lower part by slates. A portion of the roof is glazed.

The ends of the roof,—being hipped,—are formed by ribs which are in general constructed like the ordinary ones, but stronger in cross section.

One ordinary rib weighs $5\frac{1}{4}$ tons; weight of purlins, standards, &c., for one bay, $9\frac{1}{2}$ tons.

Iron work for one bay of roof weighs $14\frac{3}{4}$ tons.

Each rib is supported on a cast-iron column, 23 feet high from floor level to bottom of gutter, of an octagon section, and $1\frac{1}{2}$ inch thickness of metal. The base is also octagon, 2 feet 10 inches high, and at the bottom of 2 feet inscribed diameter. At a height of 19 feet 7 inches from floor level it widens out into an octagon capital of 2 feet 9 inches inscribed diameter at the top. The base is plain, the top is a little ornamented by raised leaves. Above that the column widens out into a kind of flat box, 4 feet 2 inches high, with a bracket in front supporting the horizontal plate to which the L irons of base of columns are bolted. The horizontal plate extends over the middle of the continued column, leaving on each side of bracket oblong openings for receiving outlets of gutters; the column changes above this horizontal plate into a vertical piece of I section, 1 ft. × $10\frac{1}{2}$ in. × $7\frac{3}{4}$ in. × $1\frac{1}{4}$ in., 4 ft. × 4 in. high. The vertical part of the base of the rib is bolted, as already mentioned, to the inner flange $10\frac{1}{2}$ inches wide. The bracket in front, being only a mere web, is hidden by a casing, appearing as an ornamental bracket of the same thickness as the flat box forming part of column, which is an elevation shaped like the two brackets supporting the outlets of gutter on each side of column. The gutter joins the column by a semi-elliptical arch forming the outlet. The casing is here required for the sake of appearance and for saving a core. To the back of upper part of column (supporting outlets and the upper flange of the I iron), a frame 11 feet 6 inches long is fixed by six 1-inch bolts. It consists of an arch of 5 feet 1 inch radius of bottom outline, with a pretty filling-in ornament, and on the top a square frame 2 feet 6 inches deep. All the main flanges are 8 inches wide, $\frac{3}{4}$ inch thick, only the upper flange of frame 1 foot wide × $\frac{3}{4}$ inch, the web being $\frac{1}{2}$-inch thick. The other end of the frame is suitably provided with a vertical flange and a lug at

the bottom for resting on the wall, being besides bolted to it by four 1-inch bolts.

This frame would apparently transmit the horizontal thrust to the walls enclosing the hall, but that is not the case. The horizontal thrust is in this roof taken by a very peculiar arrangement. On the top of the frames just described, at each end strong boxes are cast, each of which contains a pin dropped into it from above. These pins connect the ends of diagonal bracing rods, with eyes on one end and key adjustment at the other. Along the outer boxes a wrought-iron flange runs throughout the length of the building, decreasing towards the ends in strength, the diagonals increasing towards the ends. This flange, consisting of four plates, 1 ft. $\times 1\frac{1}{2}$ in., and two L irons, $3 \times 3 \times \frac{1}{2}$ in. in centre, is connected by the pins to the diagonals. On the other hand, the gutter acts as the other flange of this horizontal girder, and is made sufficiently strong, being cast $1\frac{3}{8}$ inch thick. The single lengths of gutters are connected together by means of eight 2-inch bolts, being equal in sectional area to the strength of the gutter, of course piercing the web or I-shaped part of column. The gutter being of cast-iron, and sometimes exposed to tensile strains, requires, therefore, the above-mentioned area. There are eight diagonals, one for each bay, the dimensions of the rods increase from the centre towards the ends. The diagonals having to sustain just the same as the flanges, contrary strains must be always of the same sections as them, because they can only act as the ties. At the hip of the roof only simple ties are required as diagonals.

The roof offering in its longitudinal direction a very great resistance, renders it unnecessary to provide for an extra horizontal thrust arising from wind-pressure, &c.

The gutter, being 1 ft. $\times 5\frac{1}{2}$ in. deep, 1 foot wide, and

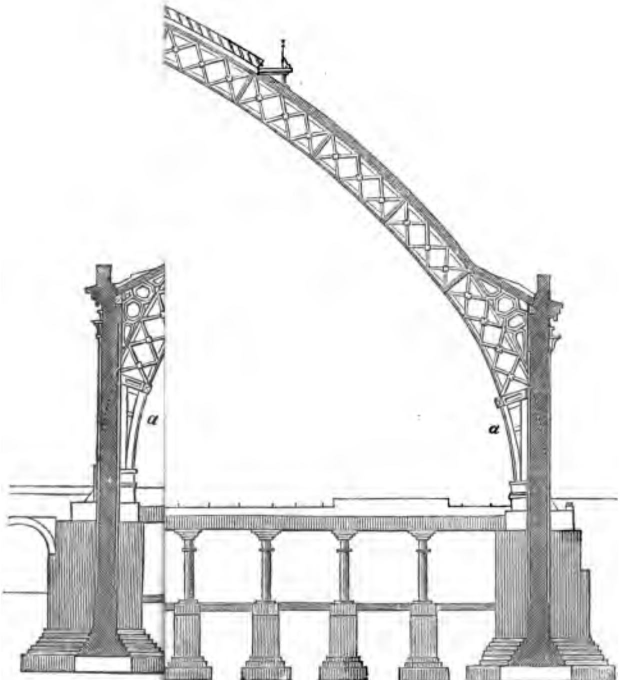
23 ft. × 4 in. long, $1\frac{3}{8}$ inches thick, has in distances of 3 feet small shoes cast on, which receive the ends of the intermediate rafters 6 in. × 3 in. The rafters are placed across the 12 foot corridor at a proper slope, laid with 1-inch boarding, and covered, like the large roof, with slates. The other ends of these rafters rest in shoes on the wall surrounding the hall. The gutter is covered by a snow grating, which is 1 ft. × 3 in. wide, and cast in lengths of 6 feet. It rests on small supports fixed by two $\frac{5}{8}$-inch bolts to cross pieces cast on the gutter at every second pair of shoes, and serving as distance pieces in the casting, while it cools and prevents it from warping into awkward shapes. These distance pieces must always be made with a top flange; otherwise the other parts of castings prove stronger in shrinking, and tear it in the middle. The rain-water is carried sideways by the bracket-shaped outlets of gutters into the column, and carried off by the same to the drain pipes. The cast and wrought ironwork of one bay of roof weighs $14\frac{3}{4}$ tons. The cast and wrought ironwork of one bay of supporting structure weighs $17\frac{3}{4}$ tons.

From the above it will be seen that the arched roof is admirably adapted for wide spans; but the best example is the colossal construction by Mr. W. H. Barlow, intended to cover the Midland Railway Station at St. Pancras Road, London. It is of larger span than any yet erected, and rises to a height of 125 feet above St. Pancras Road, covering an area of 690 feet long, by 240 feet wide in the clear.

The framework of the roof consists entirely of wrought iron, with the exception of cast iron ornamental bosses to the main principals or ribs, as shown at *a, a*, fig, 39, which are placed at 29 feet 4 inches from centre to centre, and have their intermediate ribs between them at equal distances apart, carried at every 18 feet 6 inches by trussed

[*To face page* 242.

D RAILWAY.



purlins between the main ribs. These trussed purlins are so constructed as to stiffen the bottom flanges of the main ribs in a lateral direction. One particular feature in this design is, that the thrust of the arch is counteracted by wrought iron cross beams, which form the floor for the rails and platform, and act as tie rods to the principals as they spring from the cast iron bases on each side. The wrought iron cross beams are supported on columns of cast iron, the whole forming a series of vaults and stores of great value and extent.

These are the principal features of this gigantic structure, and in order to give some idea of its magnitude, we have selected from the 'Journal of Engineering' the foregoing transverse section, as represented in fig. 39.

It might have been useful to have gone into the question of strains of this description of roof, as very little information is extant on the subject. This section has, however, been extended beyond its original dimensions, and I must leave to the engineer in chief, Mr. Barlow, Professor Rankine, or some other able mathematician, the deduction of the necessary formulæ for calculating the strains on the component parts of these important constructions.

V.

EXPERIMENTAL RESEARCHES ON INSULATION AND OTHER PROPERTIES OF SUBMARINE TELEGRAPH CABLES.*

TWENTY-FOUR years have now elapsed since Professor Wheatstone suggested to the Select Committee of the House of Commons on Railways the construction of a submarine telegraph between Dover and Calais. Since that time 11,000 miles of cable have been laid, only a little more than one-fourth of which can be said to be in a working condition; amongst the unsuccessful attempts being the Atlantic cable, measuring 2,200 miles; the Red Sea and India Telegraph, of 3,499 miles, and sundry shorter ones, measuring collectively about 2,300 miles. To account for these misfortunes is a work of some difficulty, owing to the many causes which may affect the integrity of the insulation, or the continuity of the conducting wires. The 8,000 miles of failure have not been, however, wholly lost. They have been the means of accumulating a vast amount of experience, and have suggested remedies for the inevitable difficulties which have to be encountered, now as before, both in the manufacture and in the paying-out of deep-sea cables.

There are two descriptions of cables required for marine construction: one for shallow water, where, owing to the liability of injury from ships' anchors, or the abrasion against rocks or gravel, it is necessary for the

* From the author's experiments. *Vide* Parliamentary Report on the Construction of Submarine Cables.

insulated wire to be surrounded with an extra strong covering of wire and hemp saturated with pitch; and the other for deep-sea purposes, in which case, as the cable when once laid is supposed to lie perfectly quiescent at the bottom of the ocean, no more strength nor protection is needed than will shield the wire and its insulating coating from injury during the paying-out. Respecting the shallow-water cables, in which category we class the line between Dover and Cape Grinez, laid in 1851; the line from Dover to Ostend, laid in 1853; the one from England and Hanover, 280 miles long, laid in 1858; one between Folkestone and Boulogne, laid in 1859; and one between England and Denmark, 350 miles long, also laid in 1859, all the above are the property of the Submarine Telegraph Company. In addition to these, there are several others which may come into the same class, such as the lines between England and Holland, and the Channel Islands cable, laid between this country and Alderney, Guernsey, and Jersey, in August 1858.

Amongst the most important of the *deep-sea* cables is that of the Atlantic Telegraph Company. This company obtained an act of incorporation in 1854, which conferred, amongst other privileges, the exclusive right of landing cables on the coast of Newfoundland, or the adjacent islands, for a term of fifty years. The company also obtained a grant of 14,000*l.* per annum from the British Government, and a similar one from the American Government, so long as the line was in working order.

Upon these guarantees and privileges the company was formed, and the cable was manufactured, one half by Messrs. Glass and Elliott, of Greenwich, and the other half by Messrs. Newall & Co., of Newcastle-on-Tyne. The failure of this enterprise may be attributed to the want of care and proper supervision in the manufacture, and, to use the words of the commission, 'practical men

ought to have known that the cable was defective, and to have been aware of the locality of the defects before it was laid.' We might multiply instances of several other similar failures, such as the Red Sea and India, the Spezzia and Corsica, and the Bona and Cagliari cables, all of which are now useless.

In deep-sea lines there are three points which require careful consideration, and which appear essential to success, namely—the tensile strength and conducting power of the cable, perfect insulation, and machinery calculated to pass the cable with safety from the ship into the sea. If this latter can be properly effected, we may venture to assert that a well-insulated cable, when once laid, may be retained for a series of years in satisfactory working order.

In the forthcoming Atlantic telegraph, every possible precaution has been taken to have a sound and suitable cable in the first instance, and Messrs. Glass and Elliott have not only conformed to the recommendations of the scientific committee, but they have chartered the Great Eastern steamship for the exclusive purpose of laying the cable, commencing probably at Newfoundland,* and continuing the process of paying-out, as we hope, without break or interruption, till it is safely landed at Valentia. As the construction of the cable is equally important with the skill with which it is laid at the bottom of the Atlantic, it may be interesting to compare the present cable with those previously laid down, and to show with what precaution the directors of the company have undertaken this important and precarious task.

In all the cables we have specified, the same general principles prevail, viz.:—

* On further consideration it was found desirable to commence at Valentia, as before.

1. The central conductor is a copper wire, or strand of wires.

2. The insulating covering is gutta-percha.

3. The external protection, when used, consists in most cases of iron or steel wire covered with hemp or other fibrous material, impregnated with pitch. These are wound round the central core in a spiral direction, in order to relieve the conducting wire from strain, and increase the strength of the cable.

4. The cables so prepared have been paid-out over the stern of ordinary vessels, with a pressure-break to regulate the delivery according to the speed of the vessel, which has averaged from five to six knots per hour.

In all cases copper has been chosen for the conducting wire, its durability and its high conducting power rendering it peculiarly applicable for the purpose. In the first telegraphs, the conductor generally consisted of a No. 16 copper wire. This size gave abundant area, and the resistances, even when in lengths of several miles, were not found to interfere seriously with the working. The conducting power of copper wire was taken to be directly as the area; there were, however, no precise data for determining *à priori* the size of wire requisite for any given length of circuit and speed of transmission. The wire was joined by being carefully lapped and soldered at the joint, and wrapped with smaller binding-wire, which was also soldered with silver solder. In spite of the utmost care in the construction of these joints, some were always imperfect, owing to their liability to fracture, and a break at any single joint destroyed the value of the whole cable. Moreover, the defects in the copper, owing to want of homogeneity, and the presence of foreign matter, frequently rendered the wire so weak that it ultimately parted after being covered, breaking the circuit, or stretched out and reduced the diameter to an

inconvenient extent. It was also found that, if the covered wire was excessively stretched, and then allowed to contract, the copper wire, being incapable of regaining its original dimensions, knuckled through the elastic coating.

To remedy these defects, instead of a single copper wire bundles of smaller ones, of similar area, were adopted, the joints being so distributed that the fracture, or defect, of a single wire, does not destroy the whole cable. One serious objection to this form of conductor is that, if a single wire breaks, the sharp end is liable to penetrate through the gutta-percha, and establish a communication with the outer conductor. Such a defect is not easily detected, and it can only be guarded against by close examination of the strand itself, and by the constant testing of the coating during the manufacture. In the form of a strand the bulk of the conductor is also greater, and more gutta-percha will therefore be required to cover it. It will, moreover, not be perfectly solid, but will allow water, if it happen to penetrate to any part of the wire, to pass along as in a tube. This latter objection the Gutta-percha Company propose to remove by coating the central wire of the strand with Chatterton's compound, and then bedding the six centre wires in it in the process of twisting. The compound squeezed out between the wires unites firmly with the insulating material, and the whole becomes so solid that a few inches of this cable will prevent the percolation of water at a pressure of 600 pounds per square inch. Mr. Daft proposes to obtain the same object by bedding copper wires coated with brass in vulcanised india-rubber. Mr. Clark obtains solidity by making the conductor in the shape of a solid wire, divided into three or four sections longitudinally, fitting closely to each other. Mr. Newall unites the several wires of a strand with solder.

Dr. Matthiessen, Professor Thompson, and other experimentalists, have shown that the quality of the copper exercises a material influence on the conducting power of the wire, and it is very important that copper, as pure as can be obtained in commerce, should be used.

TABLE I.

SHOWING THE CONDUCTING POWER OF CERTAIN COMMERCIAL COPPERS.

Quality of Copper.	Conducting Power.	Temperature Centigrade.	Cause of Diminution of Conducting Power.
Pure copper . . .	100· mean	15·5°	
Specimen furnished by Mr. Tennant, cut from a piece 1½ ton in weight	98·78	15·5	Traces of silver. No suboxide of copper.
American (Lake Superior)	92·57	15·	Traces of iron, silver (·03 per cent.), and suboxide of copper.
Australian (Burra Burra)	88·86	14·	Traces of iron and suboxide of copper.
Best selected . .	81·35	14·2	Traces of iron, nickel, antimony, suboxide of copper, &c.
Bright copper wire.	72·22	15·7	Traces of lead, iron, nickel, suboxide of copper, &c.
Tough copper . .	71·03	17·3	Traces of lead, iron, nickel, antimony, suboxide of copper, &c.
Russian (Demidoff)	59·34	12·7	Traces of iron, arsenic, nickel, suboxide of copper, &c. The arsenic present may be considered the chief reason of the low conducting power.
Spanish (Rio Tinto).	14·24	14·8	Two per cent. arsenic; traces of lead, iron, nickel, suboxide of copper, &c. The low conducting power is to be attributed to the arsenic present.
Gibraltar Core:—			
Specimen, No. 112	90·7	15·5	Traces of lead, suboxide of copper, iron, and antimony.
„ „ 91	89·5	15·5	
„ „ 292	78·2	15·5	Traces of lead, arsenic (very small), iron, nickel, antimony, and suboxide of copper.
„ „ 240	74·4	15·5	

The preceding table, extracted from the commissioners' report, shows the relative value, or conducting powers, of certain commercial coppers. It would appear that the difference of conducting power in the different kinds of copper is caused by the impurities contained in the specimens experimented upon; the Rio Tinto copper, in so far as regards its conducting power, being no better than iron.

It has been found that there are no alloys of copper which have a better conducting power than the metal itself; but, as perfectly pure copper is not to be obtained, we have only to reiterate that copper, as pure as can be possibly procured, is the only metal which should be used for the conducting wire of a submarine cable.

Insulation.—As copper seems to stand out prominently as the most fitting conductor, so does caoutchouc, or india-rubber, appear almost specially intended for the purpose of insulation. Its qualities, in this respect, are of the highest order. It is tough, highly elastic, of less specific gravity than water, easily manipulated, extremely durable under water, nearly impervious to moisture, except superficially, and not excessively costly; and on its first introduction it appeared as if nothing further could be desired. One of the first and most important requirements in any insulating substance is that it should offer facilities for making the numerous joints required, either in the first construction of the line or for its repair when laid down. For this purpose, also, india-rubber appeared well adapted: if after being cut the fresh surfaces are immediately brought into contact, almost perfect reunion takes place; and if they are warmed and slightly moistened with naphtha (in which india-rubber is soluble), they are hermetically sealed. The covering was effected by first coating the copper wire with cotton and shellac varnish, and then winding a thin strip of masticated india-

rubber spirally round the wire, each turn overlapping the last. Several coatings were thus put on, the union of the surfaces being secured by means of naphtha. An almost perfect insulation was the first result, the problem on which so much time and money had been expended seemed to be definitely solved, and the new material came into rapid use. A short time, however, showed the fallacy of these hopes. India-rubber, like all other gum-resins of a similar character, slowly burns or oxidises in the air, even in darkness; but when exposed openly to the weather and to sunlight this oxidisation goes on with alarming rapidity; wires hung out of doors soon become useless; the india-rubber assumed a thick gummy or semi-fluid character, and soon fell away from the wire. The joint, even when made with naphtha, was found not to be durable, and after a short time, even in unexposed situations, the coating was found loose upon the wire. Attempts were made to preserve it by enclosing it in grooved boards, and thus protecting it from the air, but in dry situations this was found to be of but little avail; and although in wet tunnels it was found to add to the durability, it was ultimately obliged to be abandoned there also.

Gutta-percha was soon proposed as a remedy for these evils. When pure, and at moderate temperatures, it is a remarkably good insulator, and, moreover, is capable of being kneaded and drawn solidly on the wire through dies, thus avoiding the infinite number of joints required when india-rubber is used. From an analysis by Professor W. A. Miller, it appears that pure gutta-percha is a hydro-carbon, consisting of—

Carbon	88·96
Hydrogen	11·04
	100·00

In commerce, however, it is mixed with resin, vegetable fibre, moisture, &c.; the latter being mechanically diffused through the mass, influencing its pliability and toughness. Commercial gutta-percha will remain unchanged for months in the air, provided light be excluded, and the temperature be not very high; and it will remain unaltered for years in water, especially if coated with Stockholm tar, and kept in the dark. It is, however, rapidly destroyed by alternated exposure to a moist and dry atmosphere, especially if the sun's rays have access to it. Professor Miller found that all the deteriorated portions had absorbed oxygen.

We have made numerous experiments upon the effect of temperature and hydrostatic pressure on both gutta-percha and caoutchouc. They necessarily occupy a very considerable time, and are otherwise difficult to perform. The general results appear to be that temperature has a very marked effect upon gutta-percha, but that pressure appears to consolidate the material, and improve the insulation, of both gutta-percha and india-rubber.

The results may be briefly stated, as follows:—With the gutta-percha in ordinary use for submarine cables, the insulation at 72° Fahr. was not one-half as good, and at 92° not one-fourth as good, as it was at 52°, and at 52° it was not one-third as good as at 32°. Perfectly pure gutta-percha was a far superior insulator, and suffered little loss of insulation, until it attained a temperature of between 72° and 92°. India-rubber and Wray's compound, which are very far superior as insulators to the gutta-percha which has been ordinarily in use, exhibit very little loss of insulating power until they attain temperatures far above 92°.

The experiments at a very high temperature showed that, whilst india-rubber withstood a heat of 200° Fahr., and Wray's compound one of 152°, gutta-percha-covered

wire was entirely spoiled at a temperature a little over 122°. At 90° to 100° gutta-percha does not change its shape, but at a higher temperature a wire, when covered with this gum, easily becomes eccentric by the mere process of coiling. Gutta-percha-covered wire should in no case be exposed to heat the exact amount of which cannot be defined and regulated. The material is therefore not a desirable one for cables which have to be conveyed through, or laid in, the tropics, unless means be found for ensuring that the cable be maintained at a low temperature.

When immersed in water, gutta-percha, india-rubber, Wray's compound, and Chatterton's compound absorb a portion. Professor Miller's experiments, in which gutta-percha and india-rubber were subjected to pressure of three tons per square inch for a period of six weeks, show that the absorption of water by gutta-percha is almost *nil* in sea-water, and only trifling, though appreciable in fresh-water. The absorption of water by caoutchouc is always sensible, the surface being rendered white and opaque. The absorption, however, only reaches to a small depth, and does not destroy, nor in any way impair, the insulating power of the subjacent portion. The white aspect disappears as the substance dries. The amount of absorption is dependent upon the extent of surface exposed to the action of the water. The insulation of specimens of gutta-percha and masticated india-rubber, experimented on by Professor Miller, was in no way impaired by immersion under pressure, but the results with virgin india-rubber were not equally satisfactory.

The experiments conducted by the author, at Manchester, on the permeability or absorption of water of different kinds of insulators under pressure, and of different degrees of temperature, give variable results, as shown in the following pages. They were instituted to

determine the value of insulators under severe pressure, and to ascertain not only the amount of absorption under a force equivalent to the known depths of the Atlantic, but to prove experimentally the properties which peculiarly belong to the material now in use for the purposes of insulation under the varied conditions of pressure, temperature, &c. This being the case, and as these experiments were carried to a much greater extent as regards pressure, we can only here give summaries of the results.

The following experiments were prosecuted at the request of the commission, with a view to determine how far the different kinds of material proposed as insulating coverings for electric submarine cables were reliable when placed at the bottom of the ocean under the pressure of the superincumbent water. It appears that all insulators which have been subjected to experiment absorb more or less water under pressure, even those that are closest in texture—such as vulcanised india-rubber and gutta-percha; and it seems that this absorption increases the longer the specimen is retained under the water, the greater the pressure to which it is subjected, and the higher the temperature of the water in which it is immersed. The very limited time which has been available for these experiments has prevented the author doing more than to indicate decisively these general facts, without determining the numerical relations of the quantities absorbed under different conditions of time, pressure, or temperature. But already the experiments point out a very important enquiry, some of the methods by which that enquiry may be prosecuted, and some of the conditions which must be attended to in order to ensure reliable and corresponding results.

Generally, in regard to insulating power, the various materials tried arrange themselves in the following order

of permeability, the first absorbing least water, and the last absorbing most:—

1. Chatterton's compound.
2. Gutta-percha.
3. Masticated india-rubber.
4. Vulcanised india-rubber.
5. Carbonised india-rubber.
6. Wray's compound.
7. Unmasticated bottle india-rubber.

The experiments on the insulating power of various cores under pressure are less complete than those on absorption, and have been prosecuted under greater difficulties and with less variety of conditions.

So far as the experiments go, however, Wray's core exhibited very high insulating powers, retaining the charge longer than any other tried. Next in order to this may be placed a core of pure india-rubber coiled in two coats over a wire, but this very rapidly lost its insulating power under pressure. Then a core of pure gutta-percha cured by the Mackintosh process; and the experiments on this are perhaps the most satisfactory of the series. The pressure was retained upon the cable for 406 hours, in which period it exhibited considerable diminution of insulation. A core of twenty alternate coats of gutta-percha and Chatterton's compound also exhibited good insulation unimpaired after 170 hours' immersion. The experiments on a core subjected to pressure in an insulating liquid before being placed in our hands gave anomalous results. The insulation increased, instead of diminishing, as the liquid dissolved out.

The first experiments have for their object the determination of the increase of weight of various insulating materials, when subjected to enormous pressure under

water. A series of insulators was selected, such as gutta-percha, india-rubber, Wray's compound, Chatterton's compound, vulcanised india-rubber, india-rubber compounded with carbon, and marine glue. Of these, suitable-sized pieces were prepared and placed in a strong steel cylinder, and subjected to pressure by means of a lever and plunger. Before their introduction into the cylinder, and whilst dry, they were carefully weighed in a delicate balance. Then, after being subjected to pressure for a shorter or longer period, as the case might be, they were again dried on the surface, and immediately weighed. The increase of weight due to the pressure under water is the measure of the quantity of water which had been absorbed, or rather forced, into the pores of the insulator.

FIG. 39.

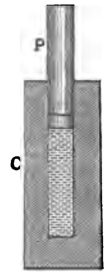


Fig. 39 represents the apparatus employed in these experiments. C is the large cylinder of steel in

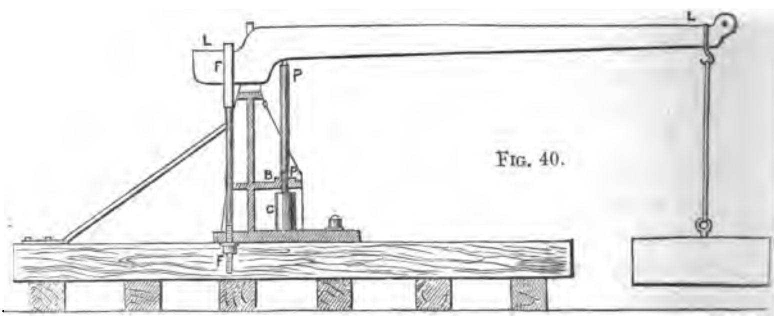


FIG. 40.

which the specimens were placed; P, its plunger, 2 inches diameter. Fig. 40 shows the general arrangement of the apparatus; L L, the large lever; F, its fulcrum; and P, the plunger of the cylinder C, in which the weighed specimens were placed. The plunger is guided vertically

by the box B, forming part of the general case or stand in which the lever is placed. By means of weights suspended on the extremity of the lever, the requisite pressure could be applied to the water in the cylinder C.

The temperature in all these experiments was low, sometimes several degrees below the freezing-point. In the first experiment with Wray's compound, the cylinder when opened was found to be filled with loose ice.

The last column of the following table shows the gutta-percha to be least absorbent, and the india-rubber most so. Wray's compound absorbed more than carbonised india-rubber, but less than pure india-rubber. The pure india-rubber appears to combine superficially with water as the surface becomes partly white, as in the present experiment, over the whole surface. The carbon appears to prevent the formation of this hydrate, and at the same time reduces the elasticity of the native rubber, and enables it to be worked more kindly.

TABLE II.

FIRST SERIES OF EXPERIMENTS ON ABSORPTION, UNDER A PRESSURE OF 20,000 LBS. PER SQUARE INCH, REDUCED TO 100 HOURS' EXPOSURE AND 10 INCHES AREA.—(Reduced results.)

No. of Experiment.	INSULATORS.	Pressure, in lbs. per sq. inch.	Equivalent Column of Water, in miles.	Duration of Exposure, in hours.	Area of Specimen, in sq. inches.	Water absorbed, in Grains.
1	India-rubber	20,000	8·720	100	10	0·177
2	India-rubber with carbon.	20,000	8·720	100	10	0·055
3	Wray's compound . . .	20,000	8·720	100	10	0·072
4	Gutta-percha	20,000	8·720	100	10	0·044

In the next series, the whole of the specimens were placed in the same cylinder, fig. 40, and remained under pressure during the same period and under the same conditions.

TABLE III.

EXPERIMENTS ON ABSORPTION, UNDER A PRESSURE OF 6,000 LBS. AND AT THE ORDINARY TEMPERATURE.—(Results reduced to 10 inches area.)

No. of Experiment.	INSULATORS.	Pressure, in lbs. per sq. inch.	Equivalent column of Water, in miles.	Duration of Exposure, in hours.	Area of Specimen, in sq. inches.	Water absorbed, in grains.	
1	India-rubber, unmasticated	5,900	2·575	450	10	3·075	
4	India-rubber, masticated .	5,900	2·575	450	10	0·023	
8	" " .	5,900	2·575	450	10	0·636	0·682
9	" " .	5,900	2·575	450	10	0·700	
10	" " .	5,900	2·575	450	10	0·711	
11	India-rubber, vulcanised .	5,900	2·575	450	10	0·146	
7	India-rubber, carbonised .	5,900	2·575	450	10	0·980	
2	Gutta-percha	5,900	2·575	450	10	0·378	0.307
3	" "	5,900	2·575	450	10	0·177	
14	" "	5,900	2·575	450	10	0·366	
5	Wray's compound . . .	5,900	2·575	450	10	0·750	0·725
13	" " . . .	5,900	2·575	450	10	0·700	
6	Chatterton's compound. .	5,900	2·575	450	10	0·375	0·279
12	" " . .	5,900	2·575	450	10	0·183	

Table III. shows that, of all the substances tried, native unmasticated india-rubber absorbs the largest quantity of water. The whole surface of the specimen had lost its black colour, and become whitened during the experiment. Taking the mean of three experiments very closely agreeing, we find that native india-rubber, after manufacture, absorbs less water than in its native state, in the proportion of 0·682 to 3·07, or as 1 : $4\frac{1}{2}$. Vulcanised india-rubber appears to be the least absorbent substance tried, but when combined with carbon, it absorbs nearly one-third more water (according to the results of this table) than in its pure masticated state. Gutta-percha and Chatterton's compound are nearly alike in their resistance to absorption, the latter being superior. In these experiments their weight increased only one-half as much as

pure india-rubber (masticated), and twice as much as vulcanised india-rubber. Wray's compound absorbed rather more than masticated india-rubber. Marine glue apparently lost instead of increased in weight.

Comparing Table II. with Tablè III., we find that the materials experimented upon are far from following the law of simple proportion in the amount of water absorbed at different rates of time. The present experiments were made under a pressure of 5,900 lbs. per square inch, and lasted for a period of 450 hours. The last were made under a pressure of 20,000 lbs., and lasted less than 100 hours. In the present experiments, carbonised india-rubber absorbed seventeen times as much as in the former; Wray's compound, ten times; gutta-percha, seven times; and masticated india-rubber, only four times. Hence it appears that, other things being equal, masticated india-rubber would be most advantageous, and carbonised india-rubber least so, as insulators; because, so far as these experiments afford data for generalising, masticated india-rubber follows a rate of absorption diminishing most with time, and carbonised india-rubber least so. This deduction, however, is complicated by the fact of a difference of pressure, and possibly of temperature, in the two experiments.

The order of merit in resisting absorption, as derived from this series of experiments, is—

1. Vulcanised india-rubber.
2. Chatterton's compound.
3. Gutta-percha.
4. Masticated india-rubber.
5. Wray's compound.
6. Carbonised india-rubber,
7. India-rubber not masticated.

The next series of experiments was made under greater

pressure, but in the same manner and for the same period of immersion.

TABLE IV.

THIRD SERIES OF EXPERIMENTS ON ABSORPTION, AT ORDINARY TEMPERATURES.
(Reduction of results to 10 inches area.)

No. of Experiment.	Insulators.	Pressure, in lbs. per sq. inch.	Equivalent Column of Water, in miles.	Duration of Exposure, in hours.	Area of Specimen, in sq. inches.	Water absorbed, in grains.	
6	Raw india-rubber . . .	15,000	6·54	450	10	1·65	
7	Masticated india-rubber .	15,000	6·54	450	10	0·22	0·26
8	" " .	15,000	6·54	450	10	0·29	
9	" " .	15,000	6·54	450	10	0·30	
10	Carbonised india-rubber .	15,000	6·54	450	10	0·29	
5	Gutta-percha	15,000	6·54	450	10	0·18	
1	Wray's compound . . .	15,000	6·54	450	10	0·56	0·57
2	" " . . .	15,000	6·54	450	10	0·58	
3	Chatterton's compound .	15,000	6·54	450	10	0·054	0·057
4	" " .	15,000	6·54	450	10	0·058	

The temperature during these experiments was generally lower than in the second series, being frequently at the freezing-point. There was loose ice in the cylinder when opened.

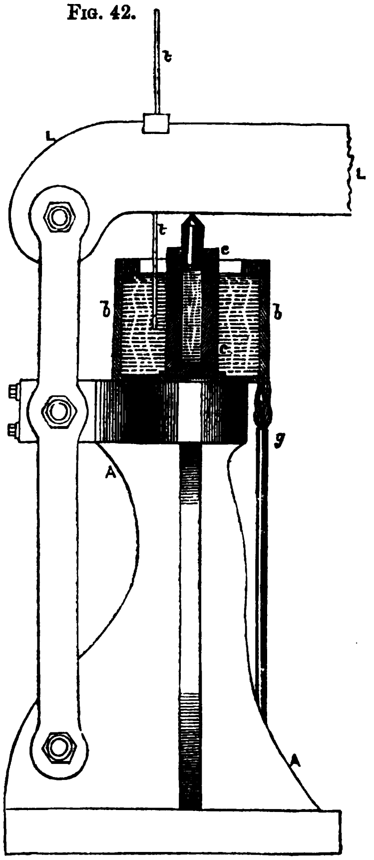
The higher pressures in these experiments seem to bring out more decisively the differences in the amount of absorption; but it is remarkable that, whilst the relative absorption does not widely differ, and the order of the insulators in their resistance to absorption is the same, the absolute quantity absorbed under greater pressure is less than in the previous series of experiments. The only discrepancy between the two series of experiments is the relatively low absorption of masticated india-rubber.

The order of merit, or power of resisting absorption, in these experiments, is—

1. Chatterton's compound.
2. Gutta-percha.
3. Masticated india-rubber.
4. Carbonised india-rubber.
5. Wray's compound.
6. Raw india-rubber.

The last in this series absorbed twenty-seven times as much as the first; gutta-percha and Chatterton's compound hold, as before, the highest place, but the superiority of the latter was more manifest; it had become whitened at the surface, but apparently the water had penetrated the thinnest possible film.

Fig. 42.



The next experiments were made with a view to determine the effect of temperature on the absorption of water by these insulators. Recourse was had to the small cylinder, *c*, fig. 42, which was surrounded by the water bath, *b*, *b*, maintained at a uniform temperature of 100° Fahr. by the gas-jet *g*. *t*, *t* is the thermometer. The lever by which the pressure was applied to the plunger is shown at L, L, attached to the firm cast-iron base, A, A.

The different substances were tried separately, as in the first series, and the weighings were repeated at intervals. During the night it was necessary to remove the gas-jet, as the uniformity of temperature could not be depended upon; hence, for half the period of immersion the specimens were at a temperature of 50° only, and for the remainder at a temperature of 100°. The loss of weight, after removal from the cylinder, in consequence of the evaporation of the water absorbed, was, in these experiments, noted, and it was found the specimens decreased in weight below their original weight when dry.

In the whole of these experiments, the pressure was 20,000 lbs. per square inch; area of specimens, 8 square inches; and thickness, about one-eighth of an inch.

TABLE V.

FOURTH SERIES OF EXPERIMENTS ON ABSORPTION, AT INCREASED TEMPERATURES.—(Results reduced to 100 hours and 10 inches area.)

No. of Experiment.	Insulators.	Pressure, in lbs. per sq. inch.	Duration of Exposure, in hours.	Temperature, Fahr. (Mean).	Area of Specimen, in sq. inches.	Water absorbed, in grains.	Loss of Weight in Drying.
3	Gutta-percha	20,000	100	75°	10	0·27	3·61
4	India-rubber	20,000	100	75	10	0·45	0·87
5	Wray's compound . . .	20,000	100	75	10	0·58	0·91
6	Chatterton's compound .	20,000	100	75	10	0·20	0·60
7	Vulcanised rubber . . .	20,000	100	75	10	0·80	2·27

Comparing the numbers in this table with those in the first series, which were made under precisely similar conditions in all respects, except temperature, which then did not exceed an average of 40° or 45° Fahr., it becomes evident that temperature has a considerable effect on the amount of water absorbed. Thus, gutta-percha at 45° absorbed 0·044 grains; at 75°, 0·27 grains, or six times as much. In like manner, india-rubber absorbed 0·177

grains at a lower temperature, and 0·45 at the higher, or two-and-a-half times as much. Wray's compound, 0·072 at the lower temperature, and 0·58 at the higher, or seven times as much.

Reasoning from the foregoing experiments, a question arises as to the ratio or quantity of water absorbed at different times, and the condition of the specimens after extended immersion. The present experiments, although showing the relative permeability of different insulators, do not afford data to determine the ultimate condition of the material intended to surround and insulate the conducting wires of the electric cable. To ascertain these facts, a much more enlarged series of experiments is required, extending over a much greater length of time. If, for example, gutta-percha absorbs ·015 grains of water in 100 hours, under a pressure of 20,000 lbs. on the square inch, we want to determine the corresponding quantity absorbed in 1,000 hours; and further, at what period will the continuous absorption cease? These are questions of vital importance as regards the porosity of the specimens; and, when ascertained, we should still require to know to what extent the insulation of the electric current would be impaired in the cable when saturated with moisture.

Should our best insulators, such as Chatterton's compound or gutta-percha, as given in the experiments, arrive at a point at which they will absorb no more water under a given pressure, it then becomes necessary that we should ascertain whether the water imbibed is sufficient to carry off the whole or a part of the voltaic current, and whether the passage of the current through the insulator would accelerate, in turn, the oxidation and consequent destruction of the conductor. To solve these questions, we require, in my opinion, as before stated, a long series of carefully-conducted experiments, which would tend to

give a reliability to these important undertakings, which at present they have not attained.

The earlier experiments on the insulating power of various cores when placed under pressure were made with voltaic electricity; but, owing to the shortness of the specimens, it was found impossible to destroy their insulation by the absorption of water so as to permit a current from a small battery to pass through the covering.

Failing in this, recourse was had to frictional electricity, which, from its high intensity, passed with greater or less facility through the insulating coverings of the wire. Still the difficulty of deciding upon the period at which, after remaining under pressure, the insulation began to grow less perfect, remained to a large extent unremoved. This difficulty was very much increased by the necessarily short period in which the experiments had to be completed. It was impossible in many cases to leave the cores long enough under pressure to ascertain clearly the entrance of water; and only in one or two instances was any defect in the cable detected, beyond question, by the gradual loss of insulating power in the specimen under trial. To inadequacy of time were added manipulative difficulties; such as the making of a packed joint which should hold tight against so enormous a pressure as 10,000 lbs. per square inch, and also the variable hygrometric condition of the atmosphere.

The earlier and preliminary experiments were made with a simple double pith ball electrometer suspended from one of the exposed ends of the cable. This method, however, did not allow of sufficient accuracy in the measurement and regulation of the charge and the rate of loss, to afford satisfactory results.

The following method was then adopted. The core was placed in a steel cylinder, E, E (figs. 43 and 44), with

the ends projecting. This cylinder was bored out to seven-eighths of an inch diameter, and at either end a pair of strong brass glands, G, G, were fitted, so as to

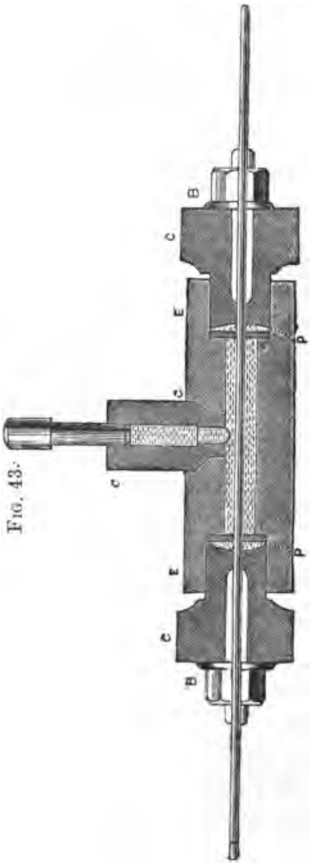


Fig. 43.

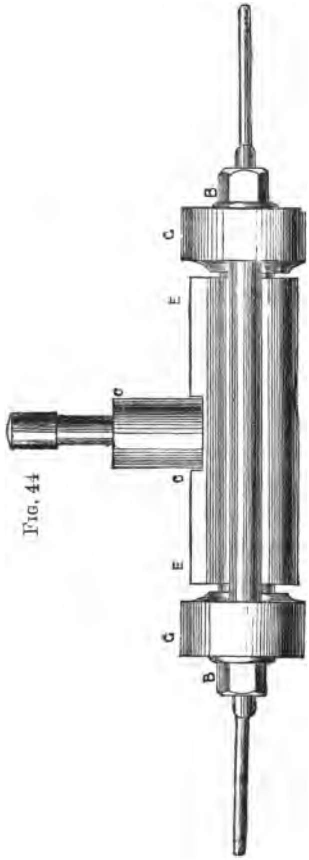


Fig. 44.

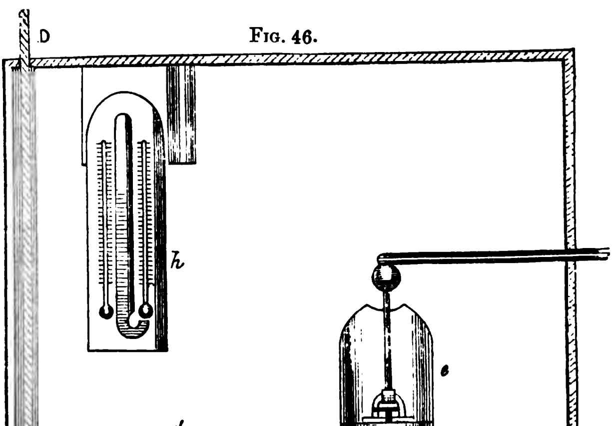
compress round the core the vulcanised india-rubber packing, P, P, by the aid of the bolts and nuts, B, B. The compression thus applied indented the core to a

greater or less degree (fig. 45) at each of the points where the india-rubber packings were applied; and this indentation was greater or less according to the pliability of the insulator. Communicating with the large cylinder,

FIG. 45.

E, E, is a small cylinder, C, C, fitted with a solid plunger. The pressure was applied, through the medium of the plunger, by a lever, L, L (fig. 42), after the cylinders had been filled with water. Up to about 10,000 lbs. pressure per square inch, or a pressure equivalent to the weight

FIG. 46.



of a column of water 4·36 miles high, the cylinder would stand without leakage; but beyond this pressure the water forced its way amongst the packings, and, either with or without external leakage, prevented the attain-

ment of any high pressure from the fall of the plunger on its bearings.

One end of the core was hermetically sealed in all but the earliest experiments. The other end was covered with a rounded brass cap, and surrounded by a closed box, D, D (fig. 46), containing dishes, *d*, of concentrated sulphuric acid, an electrometer, *e*, and a hygrometer, *h*. By means of the acid the atmosphere round the cable was kept in a tolerably uniform condition of dryness in a room otherwise damp, and the apparatus and surface of the cable maintained under similar conditions throughout the whole of the experiment.

The electrometer employed is known as the Peltier's electrometer. In this instrument the electricity being simultaneously communicated to a fixed bar and a metallic index, the latter is repelled. A directive force is given to the index by means of a small magnetic needle, in order to retain it at zero when no electric force acts upon it.

The charge was given from an electrophorus, and was ordinarily of such intensity as to deflect the needle through an arc of 70°. The fall of the needle, from loss of charge, was then watched at intervals as nearly uniform as was convenient, until the needle had sunk to 20°.

Although interesting, it would be unnecessary to give the experiments on insulation in detail, and therefore, as in the former experiments on permeability, a summary of results will suffice.

TABLE VI.

Summary of Results,

Showing approximately the time required in each for a Loss of Charge equivalent to a Fall of the Electrometer Needle of 50°.

No. of Experiment.	Description of Core.	Pressure, in lbs. per sq. inch.	Equivalent Column of Water, in miles.	Duration of Exposure, in hours.	Time required for Loss of 50°.
I.					
1, 2	Gibraltar core, cured by Macintosh	10,000	4·363	282	136′ 20″
3		10,000	4·363	328	100 0
4, 5		10,000	4·363	405	32 30
II.					
1, 2, 3	Core impregnated with insulating liquid	0	0	0	6′ 20″
4		10,000	4·363	24	11 40
5, 6		10,000	4·363	48	27 35
7		10,000	4·363	56	13 0
8, 9		10,000	4·363	77	62 0
10		10,000	4·363	120	97 0
11, 12, 13		10,000	4·363	170	105 0
III.					
1, 2	Wray's core	0	0	0	1,300′ 0″
IV.					
2	Wray's core	0	0	0	411′ 0″
V.					
2	Core impregnated with insulating liquid	10,000	4·363	4	68′ 30″
3, 4		10,000	4·363	10½	44 15
VI.					
1	Core of 20 alternate coats of gutta-percha and Chatterton's compound	0	0	0	95′ 30″
2, 3		10,000	4·363	121	42 45
5		10,000	4·363	150	118 0
6		10,000	4·363	170	100 50
VII.					
1	Core of pure india-rubber	0	0	0	443′ 0″
2		10,000	4·363	80	18 0
VIII.					
1, 2	Gutta-percha core . .	0	0	0	4′ 30″
3		10,000	4·363	264	8 0
4, 5, 6		10,000	4·363	480	4 5
7, 8		10,000	4·363	576	3 37

TABLE VI. (*continued.*)

No. of Experiment.	Description of Core.	Pressure, in lbs. per sq. inch.	Equivalent Column of Water, in miles.	Duration of Exposure, in hours.	Time required for loss of 50°.
IX.					
1	India-rubber core	0	0	0	26′ 0″
2		3,977	1·72	390	0 0
X.					
1	Silver's india-rubber core	0	0	0	380′ 0″
2		0	0	0	387 0
3		0	0	0	382 0

On a careful inspection of the above summary, it will be seen that a great difference exists in the retentive powers of the different insulators under severe pressure: these anomalies almost defy attempts at comparison. If we take No. 1, the Gibraltar core, cured by Macintosh, we have, after an immersion of 282 hours, at the enormous pressure of 10,000 lbs. per square inch, a power of retention of 136 minutes; at 325 hours' immersion, it is reduced to 100 minutes; and at 405 hours', it is still further reduced to 32 minutes, showing that the insulation is very considerably affected when a sufficiently long period of time is allowed for the permeation of the cable. In the next series of experiments, on a core impregnated with an insulating liquid, we have totally different results, as there is a steady and progressive gain in the insulating powers of the core. At 24 hours of immersion, we have 11 minutes 40 seconds; at 48 hours, 27 minutes 25 seconds; and so on till, at 170 hours, the charge is retained for a period of 105 minutes. Wray's core was too small to be fixed in the cylinder; but it retained a charge under atmospheric pressure for 1,300 minutes, and hence manifested a superiority to all the other cables tried. In another trial with a larger cable, this insulator also gave

very satisfactory results. In No. 6 core, of twenty alternate coats of gutta-percha and Chatterton's compound, there are the variable results of an increase in the first five experiments from 43 minutes in 121 hours to 118 minutes in 150 hours; whilst in the sixth experiment, the retention after 170 hours' immersion again falls to 100 minutes. These discrepancies are difficult to account for, and a more lengthened series of experiments is required for the attainment of accurate results. No. 7, a core of pure india-rubber, indicated very good insulation before the pressure was applied; but after 80 hours' immersion the insulation was almost entirely destroyed.

The very important question of insulation in deeply-submerged cables is far from having received, as yet, a complete solution. The foregoing experiments are satisfactory, in so far as they show approximately the relative porosity of various materials; but they do not point out how we are to obtain an insulator impermeable to water, and at the same time a good non-conductor. This desideratum has yet to be attained.

We might have extended our illustrations on the permeability, effects of temperature, and other conditions connected with the insulators now in use; but having already gone largely into detail, we must conclude with observing, that in the second attempt to ensure success, as regards both the manufacture and laying of the cable, a second series of elaborate experiments were instituted, under the direction of a scientific committee appointed for that purpose. The results of the experiments are satisfactory and interesting, and are given in the following article.

In conclusion, we present our readers with drawings and particulars of the two cables, showing that which failed in 1858, and that which is intended for submersion in 1865. From these will be seen the difference of weight

and strength, and judging from the precautions that are now taken to have the cable retained in water-tanks, and carefully tested before immersion, we may reasonably infer that, on or before this time next year, a successful and satisfactory telegraphic communication will be permanently established between this country and the American continent.

Since the foregoing was written, events have occurred which have disappointed the sanguine expectations of those to whom were entrusted the submergence of the Atlantic cable of last year. In no way discouraged by the loss which ensued, the directors, confident of their ultimate success, at once came to the conclusion to make not only an entirely new cable of the same construction, but to manufacture an additional length of from 600 to 700 miles, in order to complete the cable of last year, and carry it forward to Trinity Bay, Newfoundland. On this principle, the new cable now in process of manufacture (June 1866) will be paid out from Valentia to Newfoundland independently of the lost cable; and, in the event of this being successfully accomplished, the 'Great Eastern' ship and her consorts will return to the spot where the last cable was fractured, and there commence dredging for the end now safely embedded at a depth of 2,100 fathoms at the bottom of the Atlantic.

This plan of dredging for, fishing up, and catching hold of a submerged cable is one of the most important operations ever undertaken in marine telegraphy, and when the great depth and risk of breakage is considered, we are sure it will require all the care and ingenuity of the engineers to accomplish it with success.*

* For a description of the process by which this important object is to be accomplished, *vide* Appendix.

*Description of the cable submerged between Ireland and Newfoundland by the Atlantic Telegraph Company, in 1858.**—*Distance from Ireland to Newfoundland,* 1670 *nautical miles.*

FIG. 47.

ATLANTIC CABLE, 1858.

Conductor.—A copper strand, consisting of 7 wires (6 laid round one), and weighing 107 lbs. per nautical mile.

Insulator.—Gutta-percha laid on in three coverings and weighing 261 lbs. per knot.

External Protection.—18 strands of charcoal iron wire, each strand composed of 7 wires (6 laid round one), laid spirally round the core, which latter was previously padded with a serving of hemp saturated with a tar mixture. The separate wires were each $22\frac{1}{2}$ gauge, the strand complete was No. 14 gauge.

Weight in Air.—20 cwt. per nautical mile.

Weight in Water.—13·4 cwt. per nautical mile.

Breaking Strain.—3 tons 5 cwt., or equal to 4·85 times its weight in water per nautical mile; that is to say, the cable would bear its own weight in a little less than 5 miles, depth of water.

Deepest Water to be encountered, 2,400 fathoms, or less than $2\frac{1}{2}$ nautical miles.

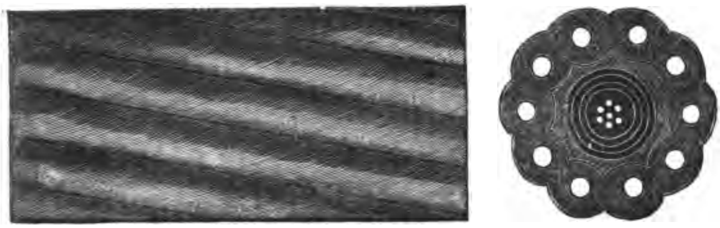
The Contract Strain was equal to 4·85 times its weight per nautical mile in water.

Length of Cable shipped.—2,174 nautical miles.

* These cables were manufactured by Messrs. Glass, Elliott, & Co., who, having joined the Gutta-percha Company, are now designated the Telegraph Construction and Maintenance Company Limited.

FIG. 48.

ATLANTIC CABLE, 1864–5.



Conductor.—Copper strand consisting of 7 wires (6 laid round one), and weighing 300 lbs. per nautical mile, embedded for solidity in Chatterton's compound. Gauge of single wire ·048 = ordinary 18 gauge. Gauge of strand ·144 = ordinary No. 10 gauge.

Insulation.—Gutta-percha, 4 layers of which are laid on alternately with four thin layers of Chatterton's compound. The weight of the entire insulation 400 lbs. per nautical mile. Diameter of core ·464, circumference of core 1·392.

External Protection.—Ten solid wires of the gauge ·095 (No. 13 gauge) drawn, from Webster and Horsfall's homogeneous iron, each wire surrounded separately with five strands of Manilla yarn, saturated with a preservative compound, and the whole laid spirally round the core, which latter is padded with jute yarn, saturated with preservative mixture.

Weight in Air.—35 cwt. 3 qrs. per nautical mile.

Weight in Water.—14 cwt. per nautical mile.

Breaking Strain.—7 tons 15 cwt., or equal to eleven times its weight in water per nautical mile; that is to say, the cable will bear its own weight in eleven miles' depth of water.

Deepest Water to be encountered.—2,400 fathoms, or less than $2\frac{1}{2}$ nautical miles.

The Contract Strain is equal to eleven times its weight per nautical mile in water.

Length of Cable shipped.—2,300 nautical miles.

Description of the Cable submerged by the Atlantic Telegraph Company, in July 1866.

FIG. 49.

NEW ATLANTIC CABLE, 1866.

Conductor.—Copper strand consisting of 7 wires (6 laid round one), and weighing 300 lbs. per nautical mile, embedded for solidity in Chatterton's compound. Gauge of single wire ·048 = ordinary 18 gauge. Gauge of strand ·144 = ordinary No. 10 gauge.

Insulation.—Gutta-percha, 4 layers of which are laid on alternately with four thin layers of Chatterton's compound. The weight of the entire insulation 400 lbs. per nautical mile. Diameter of core ·464, circumference of core, 1·392.

External Protection.—Ten solid wires of the gauge ·095 (No. 13 gauge), drawn from Webster and Horsfall's homogeneous iron, and galvanised, each wire surrounded separately with five strands of white Manilla yarn, and the whole laid spirally round the core, which latter

is padded with jute yarn, saturated with preservative mixture.

Weight in Air.—31 cwt. per nautical mile.

Weight in Water.—14¾ cwt. per nautical mile.

Breaking Strain.—8 tons 2 cwt., or equal to eleven times its weight in water per nautical mile; that is to say, the cable will bear its own weight in eleven miles depth of water.

Deepest Water to be encountered.—2,400 fathoms, or less than 2½ nautical miles.

The Contract Strain is equal to 11 times its weight per nautical mile in water.

Length of Cable to be shipped to complete both Lines.—2,730 miles.

Speed of working through the new cable, with the present improved instruments, is certified by Messrs. Thomson & Varley to be not less than eight words per minute.

Captain Douglas Galton, R.E., F.R.G.S., F.G.S., F.R.S.; William Fairbairn, Esq., C.E., LL.D., F.R.S., &c.; Charles Wheatstone, Esq., F.R.S.; William Thomson, Esq., LL.D., F.R.S., and Joseph Whitworth, Esq., C.E., F.R.S., who formed the scientific committee, appointed by the Directors of the Atlantic Telegraph Company, to examine all specimens and tenders submitted to the Company, *unanimously* recommended that Messrs. Glass, Elliott, & Co's. specimen be adopted, and that their tender for making and laying the cable be accepted.

VI.

ON THE MECHANICAL PROPERTIES OF THE ATLANTIC CABLE.*

It appeared essential to the public interest that the second attempt to submerge a telegraphic cable across the Atlantic should not be left to chance, that a close and searching investigation should be entered into, and that nothing should be left undone that could be accomplished to ensure success. For the satisfactory attainment of this object, it was considered necessary—

1st. To determine by direct experiment the mechanical properties of every cable submitted for submergence in deep water;

2nd. To ascertain the chemical properties of the insulator, and the best means to be adopted for the preservation and duration of the cable; and,

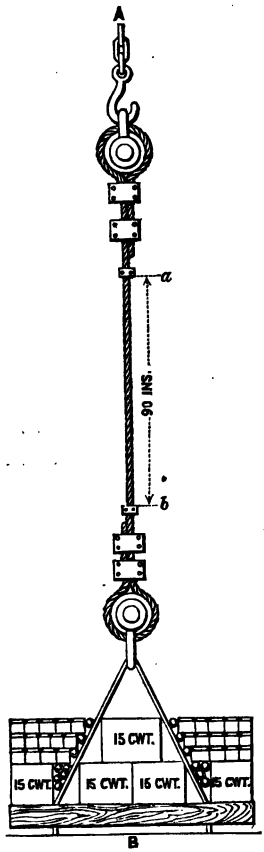
3rd. To determine the electrical properties and conditions of the cable when immersed under pressure at great depths.

These varied conditions were left to a committee, on whom devolved the consideration of every question relating to the efficiency and ultimate security of the cable. That of its mechanical properties was left in the hands of the author and he was requested to undertake the first division of the inquiry, and to determine, by

* Vide 'Transactions of the British Association for the Advancement of Science, 1864,' page 408.

actual experiment, the strengths, combinations, forms, and conditions of every cable considered of suitable strength and proportion to cross the Atlantic. To fulfil these conditions and ensure correct results, a laborious series of experiments were instituted; and in order to attain accuracy as regards the resisting powers of each cable to a tensile strain, they were broken by dead weights suspended from a crab or crane, A, by which they could be raised or lowered at pleasure. The weights were laid on one hundred-weight at a time, and the elongations were carefully taken and recorded in the table as each alternate fourth hundred-weight was placed on the scale until the cable was broken. By this process we were enabled to ascertain with great exactitude the amount of elongation in 7 feet 6 inches of the length between the two iron clips screwed round the cable, near the ends of the loops by which they were suspended, as shown in figure 50 at *a*, *b*. The hook and blocks to which the cables were attached belonged to a travelling crane that elevated or lowered the platform B, containing the weights, to heights corresponding with the stretch as the weights were laid on. Having adjusted the apparatus, the experiments proceeded in the order shown in the following Tables.

Fig. 50.



In this investigation it will not be necessary to give the experiments in detail, a summary of results will suffice.

In the following table will be found the ultimate strength of nearly all the differently manufactured cables of Great Britain, and it will be seen that they vary considerably as regards strength, ductility, &c.

TABLE I.

TABLE OF THE TENSILE BREAKING-STRAIN OF ATLANTIC SUBMARINE ELECTRIC CABLES, AS SUPPLIED BY DIFFERENT MANUFACTURERS.

Summary of Results.

Number of detailed experiment.	Description of Cable.	Breaking-weight. lbs.	Breaking-weight. tons.	Diameter of Cable, in inches.	Elongation in 8 feet length of Cable, in inches.	Elongation per unit of length.
12	Messrs. Silver & Co. .	130	·058	·35	—	—†
13	„ Silver & Co. .	354	·158	·35	—	—
1	„ Duncan	2146	·958	·77	17·10	·1781
10	„ Allan	2258	1·008	—	6·75*	·0703 (a) ·1380 (b)
11	„ Allan	2818	1·258	·67	1·67	·0169 (c)
2	„ Hall & Wells .	4946	2·007	·76	2·16	·0225
3	„ Siemens & Co. B.	5394	2·408	·77	2·60	·0270
4	„ Siemens & Co. A.	5730	2·553	·77	2·85	·0296
5	„ Glass, Elliott .	7690	3·433	1·10	3·77?	·0392?
6	„ Glass, Elliott .	7690	3·433	1·10	4·10	·0427
7	„ W. F. Henley.	9594	4·283	·85	1·85	·0191 (d)
8	„ W. F. Henley.	12786	5·708	·85	2·72	·0339 (e)
9	„ Glass, Elliott, & Chatterton	14783	6·600	1·10	3·57	·0449

(a) For outside steel wires.
(b) For copper wires.
(c) The completed cable.
(d) Without outside covering.
(e) The completed cable.

Several of these cables are of a high order of merit, and well entitled to special notice as they reached the

* This elongation refers to the inside strand of Messrs. Allan's cable.

† The elongations of Messrs. Silver and Co.'s cable, as given in the detailed experiments, are not reliable.

required point of strength—a quality of great importance in cables for submergence in deep water.

From these considerations it was deemed advisable to select a description of cable containing this element, and all the requirements to meet the contingent forces to which it might be subjected. With these impressions on the minds of the Committee, it was found desirable to select that of Messrs. Glass, Elliott & Co., which stands highest in the order of strength in the foregoing Table, and from the results in Table II., deduced from subsequent experiments on upwards of forty specimens manufactured by the same firm.

In this inquiry it will be observed that upwards of forty specimens of cables have been tested in their finished state, and this might have been sufficient for the Committee to determine the best description of cable; but it was deemed advisable to investigate still further, not only the cable as a cable, but to test experimentally each separate part, in order that every security should be afforded as to the strength and quality of the material to be employed in the construction. The whole of the specimens submitted by Messrs. Glass Elliott & Co., were composed of the same sizes of conducting wire insulated within alternate layers of gutta-percha and Chatterton's compound, which formed the core of each. Surrounding this core, were lapped, in a spiral direction, nine and in some cases ten wires, of ·089 to ·098 inch diameter; and each wire was covered with Manilla-yarn, or St. Petersburg hemp, saturated with tar and other materials. Now, as these covering wires constituted the principal strength of the cable, it was found desirable to test them separately, for the purpose of ascertaining their tenacity, ductility, elasticity &c. The wires were of three sorts, namely, steel and iron in its homogeneous or simple state of manufacture

TABLE II.

EXPERIMENTS ON THE SUBMARINE ELECTRIC CABLE OF THE ATLANTIC TELEGRAPH COMPANY. GLASS, ELLIOTT, & CO. MANUFACTURERS. DIAMETER OF CABLE 1·10 INCHES.

Summary of Results.

No. of Experiment.	Description of Cable.	Diameter of exterior wire of cable.	Breaking-weight.		Ultimate elongation in 90 inches, in inches.	Ultimate elongation per unit of length.	No. of strands.	Length of spiral lay of Cable.	Specific gravity of Cable.
			lbs.	tons.					
1	No. 5 Manilla .	·089	13,690	6·111	3·50	·0388	9	8½	1·61
2	No. 5 Hemp . .	·089	11,424	5·100	4·19	·0465	9	8½	1·69
3	No. 9 Manilla .	·083	13,104	5·850	3·75	·0416	9	8½	1·58
4	No. 16 Manilla .	·095	15,882	7·090	3·78	·0420	9	8½	1·69
5	No. 16 Hemp . .	·095	15,260	6·812	3·44	·0382	9	8½	1·76
6	No. 18 Manilla .	·097	16,876	7·533	3·82	·0425	9	8½	1·77
7	No. 18 Hemp . .	·097	13,104	5·850	2·97	·0330	10	10	1·81
8	No. 22 Manilla .	·096	16,876	7·533	3·27	·0363	10	10	1·74
9	No. 22 Hemp . .	·096	13,104	5·850	4·01	·0445	10	10	1·67
10	No. 23 Manilla .	·096	12,868	5·744	3·34	·0371	9	8½	1·71
11	No. 23 Hemp . .	·096	14,628	6·530	4·09	·0454	9	8½	1·75
12	No. 24 Manilla .	·089	16,244	7·251	3·82	·0424	9	8½	1·63
13	No. 24 Hemp . .	·089	12,432	5·550	3·68	·0409	9	8½	1·69
14	No. 25 Manilla .	·089	16,876	7·533	4·05	·0450	9	8½	1·60
15	No. 26 Manilla .	·093	14,628	6·530	3·57	·0396	9	8½	1·67
16	No. 26 Hemp . .	·093	12,544	5·600	4·18	·0464	9	8½	1·72
17	No. 27 Manilla .	·090	14,228	6·351	3·93	·0436	9	8½	1·70
18	No. 27 Hemp . .	·090	11,760	5·250	3·42	·0380	9	8½	1·77
19	No. 28 Manilla .	·095	—	—	—	—	—	—	—
20	No. 29 Manilla .	·085	13,104	5·850	3·88	·0431	10	9½	1·65
21	No. 30 Manilla .	·085	10,640	4·750	2·05?	?	10	9½	1·71
22	No. 31 Manilla .	·095	11,312	5·050	3·30	·0366	10	9½	1·74
23	No. 32 Manilla .	·095	12,432	5·550	3·01	·0334	10	9½	1·81
24	No. 33 Manilla .	·095	11,760	5·250	2·77	·0307	10	9½	1·81
25	No. 34 Manilla .	·096	13,104	5·850	3·27	·0363	10	9½	1·83
26	No. 18*a* Manilla	·097	15,260	6·812	2·32	·0257	10	9½	1·79
27	No. 35 Manilla .	·092	14,628	6·530	4·07	·0452	10	9½	1·73
28	No. 37 Manilla .	·091	13,552	6·050	3·25	·0361	10	9½	1·77
29	No. 38 Manilla .	·094	13,552	6·050	2·98	·0331	10	9½	1·69
30	No. 40 Manilla .	·095	13,226	5·904	3·02	·0335	10	9½	1·81
31	No. 42 Manilla .	·095	13,104	5·850	2·94	·0326	10	9½	1·80
32	No. 43 Manilla .	·097	17,358	7·749	2·92	·0324	10	9½	—
33	No. 46 Manilla .	·097	16,414	7·327	2·65	·0294	10	9½	—
34	No. 47 Manilla .	—	15,828	7·090	3·01	·0334	—	—	—
35	No. 48 Manilla .	—	14,092	6·291	3·04	·0351	—	—	—
36	No. 49 Manilla .	—	17,088	7·628	3·58	·0414	—	—	—

TABLE II.—*continued.*

1. Broke in centre.	19. Not tested.
2. Broke at cramps.	20. Broke in centre.
3. Broke at cramps.	21. Broke 15 inches from cramps.
4. Broke 19 inches from cramps.	22. Broke in the centre.
5. Broke 3 inches from cramps.	23. Broke 1 inch from cramps.
6. Broke 2½ inches from cramps.	24. Broke 8 inches from cramps.
7. Broke 9 inches from cramps.	25. Broke 3 inches from cramps.
8. Broke 3 inches from cramps.	26. Broke 1 inch from cramps.
9. Broke in centre.	27. Broke 3 inches from cramps.
10. Broke in bend of the barrel.	28. Broke 7 inches from cramps.
11. Broke 3 inches from cramps.	29. Broke 1 inch from cramps.
12. Broke 15 inches from cramps.	30. Broke in 3 places.
13. Broke 12 inches from cramps.	31. Broke near centre.
14. Broke at cramps.	32. Broke 1 inch from cramps.
15. Broke 27 inches from cramps.	33. Broke 3 inches from cramps.
16. Broke 12 inches from cramps.	34. Broke 3 inches from cramps.
17. Broke 8 inches from cramps.	35. Broke 1 inch from cramps.
18. Broke at cramps.	36. Broke; not registered.

N.B. In this Table the elongations are taken from the weight immediately preceding that which fractured the Cable.

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from coke, coal, and charcoal. From the samples the following results were obtained:—

From Table III. it will be seen that, out of 21 specimens experimented upon, the maximum of strength rests with Johnson, and the minimum with Jenkins, Hill & Co. the ratios being as 1950: 450, or as 4·33: 1. The maximum of elongation to that of the minimum varies with a load of 550 lbs. as the numbers ·320 for Ryland's and about ·014 for Johnson's steel wire in experiment 2,* being in the ratio of ·320: ·014, or as 22·8: 1, nearly. Softness and ductility have always been considered an important element in the construction; but this measure of ductility is probably overrated, as the Ryland wire, with the last weight laid on (50 lbs.) was sufficient to extend or stretch considerably before it broke. Viewing the subject in this light, it is obvious that a very high ductility with a low standard of strength is not what is wanted, but a combination of strength and ductility that will prevent snapping from brittleness, on the one hand, and give the

* Obtained from the detailed experiments.

requisite powers of elongation without material injury to the strength, on the other. What is therefore wanted in these wires is tenacity united to ductility in resistance to a tensile strain, without incurring fracture, up to at least seven-eighths of its ultimate strength.

TABLE III.

EXPERIMENTS TO DETERMINE THE STRENGTH AND OTHER PROPERTIES OF STEEL, HOMOGENEOUS, AND IRON WIRE, CALCULATED TO ESTABLISH A SECURE AND, AS NEARLY AS POSSIBLE, A PERFECT CABLE FOR AN ELECTRIC TELEGRAPH ACROSS THE ATLANTIC.

Summary of Results of Experiments on Bare Wires.

Number of Experiment in Table II.	Name of Manufacturer.	Diameters of wire, in inches.	Description of wire.	Breaking-weight of wire, in lbs.	Ultimate elongation in 50 inches, in inches.
1 & 2	Messrs. Taylor & Co. . .	·087	Hæmatite . .	650	·280 (*a*)
4 & 5	„ Horsfall . . .	·095	Homogeneous .	950	·366 (*b*)
6 & 7	„ Horsfall . . .	·097	Special homogeneous . . .	850	·267 (*c*)
8 & 9	„ Johnson . . .	·093	Charcoal . . .	750	·173
10 & 11	„ Johnson . . .	·098	Galvanised . .	650	·198 (*d*)
12 & 13	„ Shortridge & Co. .	·089	Homogeneous .	650	·190 (*e*)
14	„ Smith and Houghton	·091	Homogeneous .	1250	·712
16	„ Hughes	·091	Charcoal . . .	600	·198
17 & 18	„ Firth and Sons .	·088	Homogeneous .	650	·218 (*f*)
20	„ Jenkins and Hill .	·085	Soft patent steel	600	·264 (*g*)
21	„ Jenkins and Hill .	·085	Annealed steel .	450	2·760 (*h*)
22	„ Ryland Brothers .	·093	Charcoal . . .	550	·320
23	„ Taylor & Co. . .	·089	Hæmatite, S 3 .	550	·171 (*i*)
24	„ Taylor & Co. . .	·095	Hæmatite, S 4 .	750	·366 (*j*)
32	„ Horsfall, No. 7 .	—	Homogeneous, No. 7 . . .	1150	·480
33	„ Horsfall, No. 9 .	—	Homogeneous, No. 9 . . .	1050	·550
Extra. 1	„ Johnson, 1 . . .	·095	Steel wire . .	1950	·853
Extra. 2	„ Johnson, 2 . . .	·095	Patent steel . .	1950	·631
Extra. 3	„ Johnson, 1 A . .	·095	Homogeneous .	950	·346
Extra. 4	„ Johnson, 2 A . .	·095	Homogeneous .	550	·116
Extra. 5	„ Johnson, 3 A . .	·095	Special charcoal	750	·170

(*a*) ·087 in. diameter at the fracture.
(*b*) ·083 „ „ „
(*c*) ·092 „ „ „
(*d*) ·098 „ „ „
(*e*) ·088 „ „ „
(*f*) ·086 in. diameter at the fracture.
(*g*) ·083 „ „ „
(*h*) ·071 „ „ „
(*i*) ·082 „ „ „
(*j*) ·082 „ „ „

From a long series of well-conducted experiments, it has been found that a good quality of ductile iron improves in strength by elongation, that is, the whole of its fibres are brought into action by the elongation of those first subjected to strain, or, in other words, they yield up only part of their strength until the force reaches the other parts, so as to produce uniformity of action throughout the whole section of the wire. This is a property of good iron which requires to be extended to the manufacture of both steel and homogeneous wire; and taking the experiments as they exist in the foregoing series of results, I find that with proper care in the selection of the material in the first instance, a judicious system of manipulation in the second, and a rigid system of inspection and check upon the quality as delivered, from time to time, during the manufacture, that wire of homogeneous iron, ·095 inch diameter, can be made of strength sufficient to sustain from 900 to 1000 lbs. with an elongation of ·0068 or $\frac{68}{10,000}$ per unit of length. This description of iron appears to be the most suitable for the Atlantic cable, as it combines strength with ductility, and may be produced at a comparatively moderate cost. Great care is, however required to maintain, during the whole process of manufacture, the full standard adopted at starting, both as regards the strength and ductility of the wire.

It was, also, found desirable to test the separate strands of each cable, as well as the wires themselves. For this purpose a number of strands similar to those employed in the manufacture of the different cables were procured and the tensile breaking strain and elongations carefully observed and recorded. In order to ascertain whether the length of the lay of the hemp and Manilla round the strand was of that spiral which produced a maximum strength, the yarn separated from the strand was also tested, and, comparing the sum of the breaking strains of

the wire and yarn separately with the whole in combination, this object was approximately gained. The summary of results of these experiments will be seen in the two following Tables :—

TABLE IV.

TABLE OF THE TENSILE BREAKING-STRAIN OF THE YARN (TWISTED) COMPOSING THE COVERING OF THE STRANDS OF MESSRS. GLASS, ELLIOTT & Co.'s CABLES FOR THE ATLANTIC SUBMARINE TELEGRAPH.

Summary of Results on Manilla and Hemp Yarn.

No. of experiment.	Description of material.	Mean breaking weight, in lbs.	Elongation in 50 inches, in inches.	Remarks.
1 & 2	White Manilla	152	·81	Permanent set with 140 lbs. after removal of load =·52 inch.
3 & 4	White Hemp .	166	1·36	Permanent set with 160 lbs. after removal of load, 1·32 inch.
5 & 6	Tarred Manilla	137	1·35	Permanent set with 120 lbs. after removal of load =·76 inch.
7 & 8	Tarred hemp .	101	1·28	

Another very important question arises in the construction of this cable, and that is the strength of the core and its conducting wire, and how it is to be protected under a pressure of 7000 or 8000 lbs. per square inch when lodged at the bottom of the ocean. This appears a question well entitled to consideration; and provided a properly insulated wire of one or more strands can, without any exterior covering, be deposited in safety at these great depths, it is obvious that the simpler the cable, the better. Assuming, therefore, that gutta percha is the most desirable material that can be employed as an insulator, it then resolves itself into the question, What additional covering, and what additional strength, is necessary to enable the engineer to pay out of a ship a length of 1600 miles into deep water so as to deposit it without strain at the bottom of the ocean? This is one of the questions the Committee was called upon to solve, and for this very

TABLE V.

TABLE OF THE TENSILE BREAKING-STRAIN OF THE STRANDS COMPOSING THE CABLES OF MESSRS. GLASS, ELLIOTT AND CO.'S MANUFACTURE FOR THE ATLANTIC SUBMARINE ELECTRIC CABLE.

Summary of Results on Strands.

No. of Experiment.	Description of Strand.	Diameter of Cable.	Description of Wire.	Breaking-weight of strand, in lbs.	Ultimate elongation in 50 inches, in inches.	Gauge of wire, in inches.
1	Manilla. Strand of No. 25 cable . .	1·110	Smith and Houghton's homogeneous	1050	1·470	·089
2	„ „ No. 18 cable . .	1·107	Horsfall's special homogeneous . .	1550	1·336	·097
3	„ „ No. 22 cable . .	1·118	Johnson's charcoal	950	·462	·096
4	„ „ No. 16 cable . .	1·105	Horsfall's homogeneous, KC . . .	1750	1·366	·095
5	Hemp. „ No. 16 cable . .	1·040	Horsfall's homogeneous, KC . . .	1450	1·640	·095
6	Manilla. „ No. 27 cable . .	1·140	Firth and Sons' homogeneous . . .	1150	1·440	·090
7	„ „ No. 24 cable . .	1·129	Shortridge and Howell's homogeneous	750	·432	·089
8	„ „ No. 26 cable . .	1·150	Hughes's charcoal	1550	2·080	·093
9	Hemp. „ No. 23 cable . .	1·062	Johnson's galvanised	1350	2·300	·096
10	Manilla. „ No. 18*a* cable .	1·106	Hentzman and Co.'s charcoal. . .	1650	2·100	·097
11	„ „ No. 37 cable . .	1·059	Shortridge and Co.'s homogeneous .	1050	1·054	·091
12	„ „ No. 35 cable . .	1·120	Cammell and Co.'s homogeneous. .	1450	1·630	·092
13	„ „ No. 38 cable . .	1·096	Naylor Vickers's cast steel. . . .	1350	1·652	·094
14	„ „ No. 40 cable . .	1·094	Taylor and Co's homogeneous. . .	1550	1·824	·095
15	„ „ No. 42 cable . .	1·078	Hentzman's charcoal	1150	·978	·095
16	„ „ No. 32 cable . .	1·125	Taylor and Co.'s hæmatite, S 3 . .	1450	1·340	·095
17	„ „ No. 24 cable . .	1·129	Shortridge and Co.'s homogeneous .	1150	1·260	·089
18	„ „ No. 23 cable . .	1·150	Johnson's charcoal, galvanised . .	1250	1·352	·096
19	Hemp. „ No. 24 cable . .	1·065	Shortridge and Co.'s homogeneous .	850	·406	·089
20	Manilla. „ No. 43 or 46 cable	1·094?	Horsfall and Co.'s homogeneous . .	1850	1·198	·097
21	„ „ No. 46 or 43 cable	1·126?	Horsfall and Co.'s homogeneous . .	1650	·936	·097

important object the following experiments were instituted—

TABLE VI.

EXPERIMENTS TO DETERMINE THE STRENGTH OF THE CENTRAL CORE, AND MATERIALS OF WHICH IT IS COMPOSED.

Summary of Results.

No. of Experiment.	Description of Material.	Diameter of Core.	Breaking-weight, in lbs.	Elongation in 30 inches, in inches.	Permanent set in 30 inches, in inches.
1	Central core. . . .	·464	650	7·00	6·90
2	Central core. . . .	·464	630	5·72	5·64 (*a*)
3	Copper wire strand .	·144	450	6·71	6·71 (*b*)
4	Gutta-percha covering	·464	200	8·73	6·21

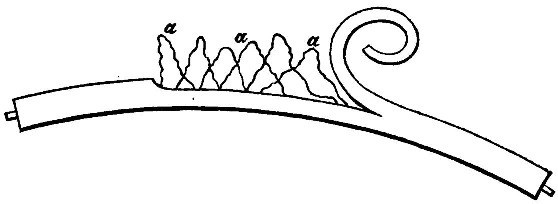
(*a*) In this experiment the core was not broken, but laid open for inspection.

(*b*) One wire broke first, and subsequently the others followed.

It is of considerable importance in marine cables to have all the parts as nearly uniform as possible, and in the foregoing experiments on the central core will be observed the difference of elasticity which exists between the copper-wire conductor and the insulator or gutta-percha covering. In the former case we have at the point of fracture an elongation of 6·71 inch and a permanent set of 6·71 inches in a length of 2 feet 6 inches, whereas in the insulating material there is 8·735 inches of extension and only 6·215 inches of a permanent set in the same length. These discrepancies of elasticity and elongation are of considerable importance, in so far as they show that in cables of this description we have to contend with materials of different properties, the first being to that of the second as 6·71 : 6·215, or as 1·08 : 1 ; in other words, the gutta-percha is 8 per cent. more elastic than the copper conducting wire which it covers. These facts account for the extraordinary development which presented itself on cutting a slice of the gutta-percha covering from the wires

which, on being liberated burst through the opening in the form of loops, as shown in figure 51, the wire bursting out in this and in a former experiment, after being forcibly stretched and liberated from its confinement, in the form shown at *a, a, a*.

FIG. 51.



From these experiments will be noticed the facility with which the copper wires elongate by tension, and that to a degree highly injurious to the gutta percha insulator, which contracts the already stretched wires, producing a tendency to force themselves in loops through the covering in which they are encased. To prevent these injurious effects it is necessary to protect the core by an outside covering of strong material, to relieve it from severe tension, and also to protect the gutta percha from injury.

Regarding this as a circumstance of great importance bearing directly upon the ultimate strength of the cable, the Committee arrived at the conclusion that the cable, No. 46, composed of homogeneous wire, calculated to bear not less than from 850 to 1,000lbs. per wire, with a stretch of $\frac{5}{10}$ths of an inch in 50 inches, was the most suitable for the Atlantic Cable.

Impressed with these views the Committee therefore recommended this cable, the particulars of which will be seen in the following specification :—

Specification of No. 46 Cable.

The conductor consists of a copper strand of seven wires (six laid round one), each wire gauging ·048 (or No. 18 of the Birmingham wire-gauge), the entire strand gauging ·144 inch (or No. 10 Birmingham gauge) and weighing 300 lbs. per nautical mile, embedded for solidity in the composition known as 'Chatterton's Compound.'

The insulator consists of gutta percha, four layers of which are laid on alternately with four thin layers of Chatterton's compound, making a diameter of the core of ·464 inch and a circumference of 1·392 inch. The weight of the entire insulator is 400 lbs. per nautical mile.

The External Protection.—This is in two parts. First the core is surrounded with a padding of soft jute yarn, saturated with a preservative mixture. Next to this padding is the protective covering, which consists of ten solid wires of the gauge ·095 inch, drawn from homogeneous iron, each wire surrounded separately with five strands of Manilla yarn saturated with a preservative compound, the whole of the ten strands thus formed of the hemp and iron being laid spirally round the padded core.

The weight of this cable in air is 34 cwt. per nautical mile; the weight in water is 14 cwt. per nautical mile. The breaking-strain is 7 tons 15 cwt., or equal to 11 times its weight per nautical mile in water, that is to say, if suspended perpendicularly, it would bear its own weight in 11 miles' depth of water. The deepest water to be encountered between Ireland and Newfoundland is about 2,400 fathoms; and one mile being equal to 1,014 fathoms, therefore $1014 \times 11 = \frac{11154}{2400} = 4{\cdot}64$, the cable having thus a strength equal to 4·64 times of its own vertical weight in the deepest water.

In this report we have not entered upon the process of immersion, either in tanks or the sea; we have confined our attention exclusively to the cable and the quality of the materials of which it should be composed, and the questions of coiling, shipping, submersion, &c., we have left for the consideration and skill of the company's engineers.

VII.

EXPERIMENTS TO DETERMINE THE EFFECT OF IMPACT, VIBRATORY ACTION AND LONG-CONTINUED CHANGES OF LOAD ON WROUGHT-IRON GIRDERS.*

A QUESTION of great importance to science and the security of life and property has been left in abeyance for a number of years,—namely, to determine by direct experiment to what extent vibratory action, accompanied by alternate severe strains, affects the cohesive force of bodies. It is immaterial whether the body be crystalline, homogeneous, or elongated into fibre, such as cast or wrought iron; the question to be solved is, how long will a body of this description sustain a series of strains produced by impact (or the repeated application of a given force) before it breaks? In the case of bridges and girders, this is a subject on which no reliable information has yet been given which may be considered as a safe measure of strength for the guidance of the architect and engineer. It is true that regulations have been established by the Lords Commissioners for Trade; but they appear to have had their origin on limited data, and in cases where the material and workmanship are good they may be relied upon as sufficient for the public safety. What, however, is wanted is experimental data to enable

* 'Philosophical Transactions,' 1864, p. 311.

the engineer to comply satisfactorily with the conditions of the Board of Trade, and cordially to unite with the Government in affording ample security to constructions in cases where the lives of the public are at stake.

To remove all doubts on this question, I have been enabled, through the liberality and at the request of the Board of Trade, to undertake a series of experiments to determine, or to endeavour to ascertain, whether a continuous change of load, and the strains produced by those changes, have any effect (and to what extent) upon the ultimate strength of the structure,—or, in other words, to ascertain the rate of endurance the material is able to sustain under these trials.

To comply with this request, a wrought-iron beam was constructed, representing the girders of a bridge of questionable strength, to be employed to determine, experimentally, the strength and durability of such a structure. This beam was made of the ordinary construction, of moderately good, but not the best quality of iron, and subjected to vibration and a perpetual change of load until the cohesive powers of the material were destroyed.

Of the resisting-powers of material under the severe treatment of a continuous change of strain, such as that which the axles of carriages and locomotive engines undergo when rolling over iron-jointed rails and rough roads, we are very imperfectly informed. Few facts are known, and very few experiments have been made bearing directly on the solution of this question. It has been assumed, probably not without reason, that wrought iron of the best and toughest quality assumes a crystalline structure when subjected to long and continuous vibration —that its cohesive powers are much deteriorated, and it becomes brittle, and liable to break with a force considerably less than that to which it had been previously subjected. This is not improbable; but we are appa-

rently yet ignorant of the causes of this change, and the precise conditions under which it occurs.

In the year 1837 I instituted a long series of experiments to determine an important quality in the strength of materials, viz. the powers of crystalline bodies to sustain pressure for an indefinite period of time, and to ascertain whether cast iron, when subjected by a given weight to long-continued transverse strain, would or would not be subject to a fracture.

It appears that former writers on the transverse strength of materials had come to the conclusion that the bearing-powers of cast iron were confined within the limits of that force which would produce a permanent set, and that it would be unsafe to load this material with more than one-third of the weight necessary to break it. This assumption is incorrect, as in the experiments to which we refer some of the bars, six in number, were loaded within one-tenth of the weight that would break them.

From these experiments it was ascertained that cast iron, when sound, is more to be depended upon, and exhibits greater tenacity in resisting long-continued heavy strains, than is generally admitted, and its bearing-powers have deserved a much higher reputation than has at any former period been given to them. This is even more apparent with wrought iron, as it is safer, being more tenacious and ductile, and less liable to flaws and imperfections, which, too, should they exist, are much more easily detected than in cast iron.

The experiments, as respects the effects of time, on loaded cast-iron bars 1 inch square and 4 feet 6 inches between the supports, were exceedingly curious and interesting. They embraced a period of seven years, from 1837 to 1844, when they were discontinued, — the heaviest-loaded bars continuing to sustain their load

without any apparent increase in the deflection. The deflections were taken monthly and carefully recorded, and the following Table exhibits the changes that took place in both the hot- and cold-blast iron-bars from June 1838 to June 1842. It is satisfactory to observe that during the whole time of the experiments the bars, whether loaded with the lighter or heavier weights, exhibited little or no change beyond what may be traced to the variations of temperature. One of the bars was, however found broken, but whether from accident or the effects of continued strain I am unable to determine. I am inclined to believe that the former was the case, as the corresponding bars retained their position, indicating changes so exceedingly small as to be scarcely perceptible, even when examined by the microscope and our best instruments.

TABLE I.

Deflections produced with permanent Weights on hot- and cold-blast cast-iron Bars 4 feet 6 inches between the Supports.

Cold-blast, Weight in lbs.	Deflection, in inches.	Date of observation.	Temperature, Fahr.	Hot-blast, Weight in lbs.	Deflection, in inches.
336	1·316	June 23, 1838.	78°	336	1·538
336	1·308	April 19, 1842.	58°	336	1·620
392	1·824	June 23, 1838.	78°	392	1·803
392	1·828	April 19, 1842.	58°	392	1·812
448	1·457	June 23, 1838.	78°	448	
448	1·449	April 19, 1842.	58°	448	

From the above it will be seen that there is no increase in the deflection of the cold-blast bar with the 336 lb. load, but a slight increase of ·082 of an inch in the hot-blast. With the 392 lbs. there is a slight and progressive increase in both bars, and in those with a load of 448 lbs. there is no change but what is due to the difference of 20° of temperature between the month of June

and that of April. As respects the load of 448 lbs., it is proper here to observe that the hot-blast bars broke at once with that weight, and one of the cold-blast bars also broke after sustaining the load 37 days, but whether by accident or from vibration is not determined. It is, however, evident from the breaking of the hot-blast bars, and one of the cold-blast, that the load of 448 lbs. approximated very close on the point of fracture, and that the slightest vibration of the floor would break the bar.

Viewing the subject in this light, it would appear from these experiments that time is an element which in a greater or less degree affects the security of materials when subjected to long-continued pressure. It may at first sight appear that the cohesive powers and the resistance may be so nicely balanced as to neutralise each other, and in this state would continue to sustain the load in that condition *ad infinitum*, provided there be no disturbing force to produce derangement of the parts, and thus destroy the equilibrium of the opposing forces. This cannot, however, be expected, and we may reasonably, under ordinary conditions of disturbance, conclude that long-continued strain will tend to lessen the cohesive force which unites the particles of matter together, and ultimately destroy that power of resistance so strongly exemplified in the above experiments. (Vide Report, Transactions of the British Association for 1842.)

As the object of this inquiry is to ascertain the limit of safety in structures, such as railway bridges, subjected to vibration and impact from a rolling load, it may be necessary, for the purpose of illustration, to refer to experiments made by the Commission appointed in 1848 to inquire into the application of iron to railway structures. In these inquiries the late Professor HODGKINSON and Professor WILLIS entered elaborately into the experi-

mental as well as the mathematical investigation: but the experiments which bear more directly upon the present inquiry are those of Captain HENRY (now Sir HENRY) JAMES and Captain GALTON, for determining the effects produced by passing weights over bars at different velocities, and subjecting others to reiterated strain corresponding to loads equal to some fractional part of the breaking-weight. The latter experiments were made with cams, caused to revolve by steam machinery, which depressed the bars and allowed them to resume their natural position for a great number of times. Two cams were used; one communicated a highly vibratory motion to the bar during the deflection, and the other greatly depressed the bar subjected to it, and released it suddenly when the ultimate deflection due to the load had been obtained, the rate of deflections being from four to seven per minute. Three bars, subjected by the first-mentioned cam to a deflection equal to what would have been produced by one-third of the statical breaking-weight obtained from similar bars, received 10,000 successive depressions, and when afterwards broken by statical pressure, bore as much as similar bars subjected to dead weight only. Of two bars subjected to a deflection equal to what would have been caused by half the statical breaking-weight, one broke with 28,602 depressions, the other withstood 30,000, and did not appear weakened to resist statical pressure.

Of the bars subjected to the second cam, three bore 10,000 depressions, each giving it a deflection equal to what would be produced by one-third of the statical breaking-weight, without having their strength to resist statical pressure apparently at all impaired; one broke with 51,538 such depressions, and one bore 100,000 without any apparent diminution of strength; whilst three bars, subjected by the same cam to a deflection

equal to what would be produced by half the statical breaking-weight, broke with 490, 617, and 900 depressions respectively. It must, therefore, be concluded that iron bars will scarcely bear the reiterated application of one-third their breaking-weight without injury.

A bar of wrought iron 2 inches square in section and 9 feet long between the supports, was subjected to 100,000 depressions, by means of the first-mentioned or rough cam, each depression producing a strain corresponding to about $\frac{5}{9}$ths of the strain that permanently injured a similar bar. These depressions only produced a permanent set of ·015 inch.

Three wrought-iron bars were subjected to 10,000 depressions each from the step-cam, depressing them through $\frac{1}{3}$ inch, $\frac{2}{3}$ inch, and $\frac{5}{6}$ inch respectively, without producing any perceptible permanent set. A bar depressed through 1 inch obtained a set of ·06 inch, and one depressed 300 times through 2 inches acquired a set of 1·08 inch. The largest deflection which did not produce any permanent set appears, by an experiment on a similar bar, to be that due to rather more than half the statical weight which permanently injured it.

A small box girder of boiler-plate riveted, 6 in. by 6 in. in section and 9 ft. long, was also subjected to depressions by means of the rough cam, principally with the view of ascertaining whether any effect would be produced on the rivets by the repeated strain; but a strain corresponding to 3752 lbs. repeated 43,370 times did not produce any appreciable effect.

From the experiments made by the Commissioners it may be inferred—

1st. That cast-iron bars or girders are not safe when subjected to a series of deflections due to one-half the load that would break them.

2nd. That they are perfectly secure in sustaining a

dead weight not exceeding one-third of the weight that would break them; and

3rd. That these reiterated deflections appear to have no injurious effect upon the metal from which the bars were cast.

As respects wrought iron, it appeared from the experiments, that a progressive increase in the deflections and permanent set was observable during every depression produced by the same cam as that employed on the cast-iron bars, exhibiting great deficiency in its elastic powers. Where the bar retained its power of restoration up to 30,000 deflections, with 10,000 more changes it took a set of ·06 inch, and from that number, with 810 additional depressions, the set increased to 1·84 inch, evidently showing that it would have continued still further to increase until the bar was rendered useless.

Comparing these experiments with those obtained from the riveted wrought-iron beam in the following experiments it will be found that a load equivalent to one-fourth the breaking-weight produced no visible change nor any permanent set after being subjected to 1,000,000 depressions of ·17 and ·22 inch. By increasing the load from one-fourth to two-fifths, it sustained 5175 additional deflections of ·22 inch, when it broke. The difference between the experiment on the wrought-iron bar and the wrought-iron manufactured girder consists in the greater rigidity of the latter, and in its increased power of resistance to vibration and the force of impact, the weight on the girder descending upon it by the force of gravity.

The institution of experiments for the purpose of ascertaining the value of wrought-iron riveted plates, in the form of tubes, through which a railway train should pass, was a conception which led to a new era in the history of bridges, and ultimately effected the passage of the estuary of the Conway and the Menai Straits. These experiments

not only gave the form and strengths required for the construction of these colossal structures, but they developed an entirely novel system of constructive art, and established the principle on which wrought-iron bridges should in future be made. Since then some thousands of bridges, many of them of great span, have been constructed, composed entirely of wrought-iron, and are now in existence supporting railways and common roads to an extent hitherto unknown in the history of bridge-building, and such as could not have been accomplished by any other description of material than malleable iron or steel.

The construction of the Britannia and Conway bridges in the tubular form led to other constructions, such as the tubular girder, the plate and lattice girder, and other forms, all founded on the principle developed in the construction of the large tubes as they now span the Conway and the Menai Straits. In the tubular bridges, it was first designed that their ultimate strength should be six times the heaviest load that could ever be laid upon them, after deducting half the weight of the tube. This was considered a fair margin of strength; but subsequent considerations, such as generally attend a new principle of construction with an untried material, induced an increase of strength, and, instead of the ultimate strength being six times, it was increased to eight times the weight of the greatest load.

The stability and great success of these bridges gave increased confidence to the engineer and the public, and for several years the resistance of six times the heaviest load was considered an amply sufficient margin of strength.

Owing to the success of these undertakings, there was a general demand for wrought-iron bridges in every direction, and numbers were made without any regard to first principles, or to the law of proportion necessary to be observed in the sectional areas of the top and bottom

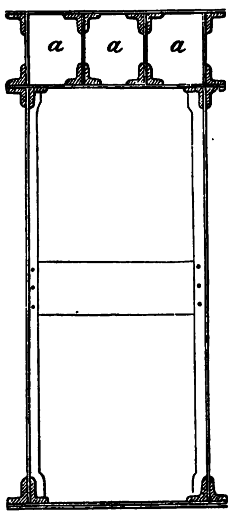
flanges, so clearly and satisfactorily shown in the early experiments. The result of this was a number of weak bridges, many of them so disproportioned in the distribution of the material as to be almost at the point of rupture with little more than double the permanent load. These discrepancies, and the erroneous system of contractors tendering by weight, led not only to defects in the principle of construction, but the introduction of bad iron and, in many cases, equally bad workmanship. Now there is no construction which requires greater care and more minute attention to sound principles than *wrought-iron girders*, whether employed for bridges of large or small span or for buildings. The lives of the public entirely depend upon the knowledge and skill of the engineer, and the selection of the material which he employs.

The defects and break-downs which followed the first successful application of wrought iron to bridge-building led to doubts and fears on the part of engineers; and many of them contended for eight, and even ten times the heaviest load as the safe margin of strength. Others, and amongst them the late Mr. Brunel, fixed a lower standard; and I believe that gentleman was prepared in practice to work up to one-third or two-fifths of the ultimate strength of the weight that would break the bridge. Ultimately it was decided by the authorities of the Board of Trade, but from what data I am not informed, that no wrought-iron bridge should with the heaviest load exceed a strain of 5 tons per square inch. Now on what principle this standard was established does not appear; and on application to the Board of Trade the answer is, that 'The Lords Commissioners of Trade require that all future bridges for railway traffic shall not exceed a strain of 5 tons per square inch.'

The requirement of 5 tons per square inch on the part of the Board of Trade is not sufficiently definite to secure

in all cases the best form of construction. It is well known that the powers of resistance to strain are widely different with wrought iron, according as we apply a force of tension or compression; it is even possible so to disproportion the top and bottom areas of a wrought-iron girder calculated to support six times the rolling load, as to cause it to yield with little more than half the ultimate strain or 10 tons on the square inch. For example, in wrought-iron girders with solid tops it requires the sectional area in the top to be nearly double that of the bottom, to equalise the two forces of tension and compression; and unless these proportions are strictly adhered to in the construction, the 5-ton strain per square inch is an error which may lead to dangerous results. Again, it was ascertained from direct experiment that double the quantity of material in the top of a wrought-iron girder was not the most effective form for resisting compression. On the contrary, it was found that little more than half the sectional area was required, and, when converted into rectangular cells similar to *a*, *a*, *a*, was in its powers of resistance equivalent to double the area when formed of a solid plate. This discovery was of great value in the construction of tubes and girders of wide span, as the weight of the structure itself (which increases as the cubes, and the strength only as the squares) forms an important part of the load to which it is subjected. On this question it is evident that the requirement of the Board of Trade cannot be applied in

Fig. 52.



both cases, and is therefore ambiguous as regards its application to different forms of structure. In the 5-ton per square inch strain there is not a word said about the dead weight of the bridge; and we are not informed whether the breaking weight was to be so many times the applied weight plus the multiple of the load, or, in other words, whether it included or deducted the weight of the bridge itself.

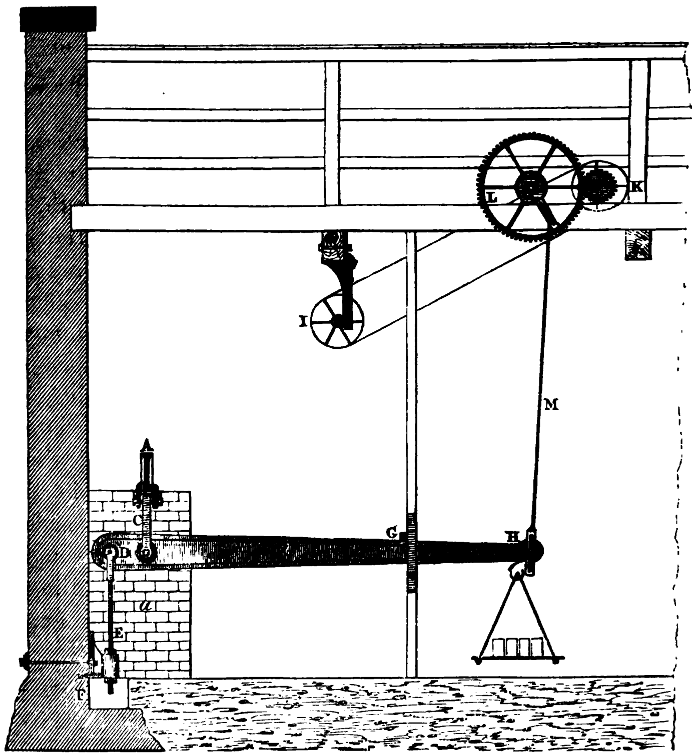
These data are wanting in the railway instructions; and until some fixed principle of construction is determined upon, accompanied by a standard measure of strength, it is in vain to look for any satisfactory result in the erection of road and railway bridges composed entirely of wrought iron.

I have been led to inquire into this subject with more than ordinary care, not only on account of the imperfect state of our knowledge, but from the want of definite instructions from the authorities whose duty it is to secure the safety of bridges and to protect the public from malconstructions. To accomplish this, I have in the following experimental researches endeavoured to arrive at the extent to which a bridge or girder of wrought iron may be strained without injury to its ultimate powers of resistance. And also to ascertain the exact amount of load to which a bridge may be subjected without endangering its safety, or, in other words, to determine the fractional strain of its estimated powers of resistance.

To arrive at correct results and to imitate as nearly as possible the strain to which bridges are subjected by the passage of heavy railway trains, the apparatus specially adapted for that purpose was designed to lower the load quickly upon the beam in the first instance, and subsequently to produce a considerable amount of vibration,

as the large lever with its load and shackle was left suspended upon it in the second. The apparatus was

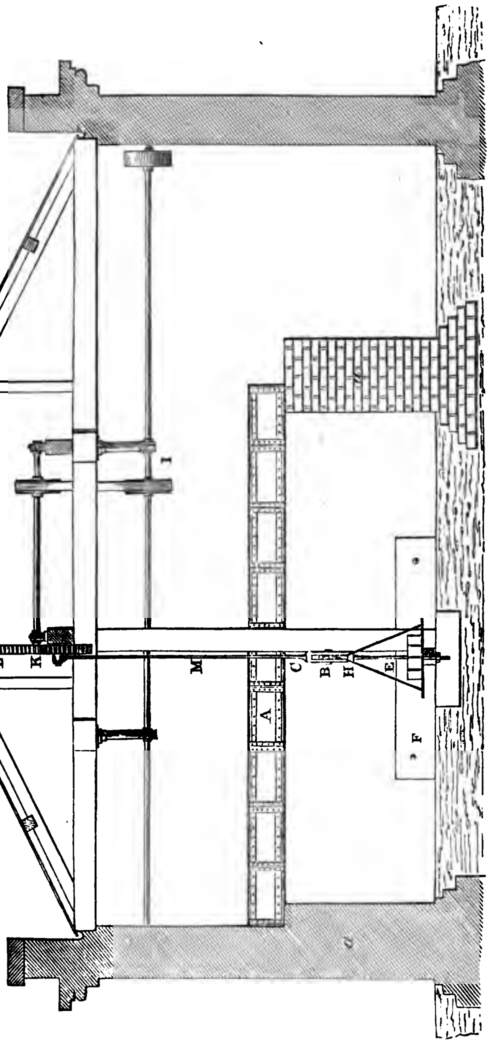
Fig. 53.



ELEVATION OF THE APPARATUS EMPLOYED FOR ASCERTAINING THE EFFECT OF IMPACT, VIBRATORY ACTION, AND LONG-CONTINUED CHANGES OF LOAD ON WROUGHT-IRON GIRDERS.

sufficiently elastic for that purpose, as may be seen on reference to the drawings.

Fig. 54.



CROSS SECTION OF THE APPARATUS EMPLOYED FOR ASCERTAINING THE EFFECT OF IMPACT, VIBRATORY ACTION, AND LONG-CONTINUED CHANGES OF LOAD ON WROUGHT-IRON GIRDERS.

The beam A, Figs. 53 & 54, is composed of an iron plate riveted with angle-irons, 22 feet long, $\frac{1}{8}$ of an inch thick, and 16 inches deep.

It was supported on two brick piers 20 feet apart. Beneath the bottom flange is fixed the lever B, which, by means of the link and shackle C, grasps the lower web of the beam close to the fulcrum D. This fulcrum, on which the lever oscillates, is formed of a vertical bar E, which acts as a standard, and has screw-nuts to regulate the height from the cast-iron plate F to the fulcrum D. The machinery for lifting the lever and scale at H consists of the shaft and pulley I, driven by a water-wheel; and from this shaft the apparatus for lifting the load is worked by a strap from the pulley on the pinion-shaft K, which drives the shaft and spur-wheel L, giving motion to the connecting rod M. This rod has an oblong slot at its lower end, in which the pin at the end of the lever works. From this description it will be seen that, in turning the spur-wheel L, the weight is not raised until the bottom of the slot comes in contact with the pin of the lever, when the load is taken entirely off the beam. That being accomplished, the connecting rod descends, when the load is again laid upon the beam and left suspended with a vibratory motion for some seconds, until the remainder of the stroke is completed, when the connecting rod again rises for the succeeding lift. In this way the weights are lifted off and replaced alternately upon the beam at the rate of seven to eight strokes per minute. The apparatus was worked night and day by a water-wheel, and the number of changes registered by the counter attached to the vertical post at G.

The girder subjected to vibration in these experiments was a wrought-iron plate beam of 20 feet clear span, and of the following dimensions: —

		inches.	
Area of top,	1 plate 4 inches × $\frac{1}{2}$ inch . . .	2·00	
„	2 angle-irons 2 × 2 × $\frac{5}{16}$ . . .	2·30	
			4·30
Area of bottom,	1 plate 4 inches × $\frac{1}{4}$ inch . .	1·00	
„	2 angle-irons 2 × 2 × $\frac{3}{16}$ . .	1·40	
			2·40
Web,	1 plate 15$\frac{1}{4}$ × $\frac{1}{8}$		1·90
	Total sectional area		8·60

Depth . . . . 16 inches.
Weight . . . . 7 cwt. 3 qrs.
Breaking-weight (calculated) . . . . 12 tons.

The beam having been loaded with 6643 lbs., equivalent to one-fourth of the ultimate breaking-weight, the experiment commenced as follows:—

TABLE II.

EXPERIMENT ON A WROUGHT-IRON BEAM WITH A CHANGING LOAD EQUIVALENT TO ONE-FOURTH OF THE BREAKING-WEIGHT.

Date. 1860.	Number of changes of load.	Deflection produced by load.	Remarks.
March 21 . .	0	0·17	
„ 22 . .	10,540	0·18	
„ 23 . .	15,610	0·16	
„ 24 . .	27,840	... ...	Strap loose, and failed to lift the weight
„ 26 . .	46,100	0·16	
„ 27 . .	57,790	0·17	
„ 28 . .	72,440	0·17	
„ 29 . .	85,960	0·17	
„ 30 . .	97,420	0·17	
„ 31 . .	112,810	0·17	
April 2 . .	144,350	0·16	
„ 4 . .	165,710	0·18	
„ 7 . .	202,890	0·17	
„ 10 . .	235,811	0·17	
„ 13 . .	268,328	0·17	
„ 14 . .	281,210	0·17	
„ 17 . .	321,015	0·17	
„ 20 . .	343,880	0·17	The strap broke

TABLE II.—*continued.*

Date, 1860.	Number of changes of load.	Deflection produced by load.	Remarks.
April 25 . .	390,430	0·17	
„ 27 . .	408,264	0·16	
„ 28 . .	417,940	0·16	
May 1 . .	449,280	0·16	
„ 3 . .	468,600	0·16	
„ 6 . .	489,769	0·16	
„ 7 . .	512,181	0·16	
„ 9 . .	536,355	0·16	
„ 11 . .	560,529	0·16	
„ 14 . .	596,790	0·16	

The beam having undergone above half a million changes of load, by working continuously for two months, night and day, at the rate of about eight changes per minute, without producing any visible alteration, the load was increased from one-fourth to two-sevenths of the statical breaking-weight, and the experiment proceeded with till the number of changes of load reached a million.

TABLE III.

EXPERIMENT ON THE SAME BEAM WITH A LOAD EQUIVALENT TO TWO-SEVENTHS OF THE BREAKING-WEIGHT, OR NEARLY THREE AND A HALF TONS.

Date, 1860.	Number of changes of load.	Deflection in inches.	Remarks.
May 14 . .	0	0·22	In this Table the number of changes of load is counted from 0, although the beam had already undergone 596,790 changes, as shown in the preceding Table.
„ 15 . .	12,623	0·22	
„ 17 . .	36,417	0·22	
„ 19 . .	53,770	0·21	
„ 22 . .	85,820	0·22	
„ 26 . .	128,300	0·22	
„ 29 . .	161,500	0·22	
„ 31 . .	177,000	0·22	
June 4 . .	194,500	0·21	
„ 7 . .	217,300	0·21	
„ 9 . .	236,460	0·21	
„ 12 . .	264,220	0·21	
„ 16 . .	292,600	0·22	
„ 25 . .	375,650	0.23	At this point the operations were suspended, the beam having suffered a million changes of load.
„ 26 . .	403,210	0·23	

The beam had now sustained one million changes of load without any apparent injury; it was then considered necessary to increase the load to 10,486 lbs., or two-fifths of the breaking-weight, when the machinery was again put in motion. With this additional weight the deflections were increased, with a permanent set of ·05 inch, from ·23 to ·35 inches, and after sustaining 5175 changes, the beam broke by tension a short distance from the middle. It is satisfactory here to observe that during the whole of the 1,005,175 changes none of the rivets were loosened or broken.

TABLE IV.

BEAM REPAIRED.

The beam fractured in the preceding experiment was repaired by replacing the broken angle-irons on each side, and putting a patch over the broken plate equal in area to the plate itself. Thus repaired, a weight of three tons was placed on the beam, equivalent to one-fourth of the breaking-weight, when the experiments were again continued as before.

Date.	Number of changes of load.	Deflection in inches.	Permanent set, in inches.	Remarks.
1860 August 9. .	158	......	......	The load during these changes was equivalent to 10,500lbs., or 4·6875 tons at the centre. With this weight the beam took a large but unmeasured set.
Aug. 11 . .	12,950	......	......	During these changes the load on the beam was 8025 lbs., or 3·58 tons.
„ 12 . .	25,900	0·22	?	
Aug. 13 . .	25,900	0·18	0	Load reduced to 2·96 tons, or ¼th of the breaking-weight.
„ 16 . .	46,326	0·18	0	
„ 20 . .	71,000	0·18	0	
„ 24 . .	101,760	0·18	0	
„ 25 . .	107,000	0·18	0	
„ 31 . .	135,260	0·18	0·01	

TABLE IV.—*continued.*

Date.	Number of changes of load.	Deflection in inches.	Permanent set, in inches.	Remarks.
1860				
Sept. 1 . .	140,500	0·18	0·01	
„ 8 . .	189,500	0·18	0·01	
„ 15 . .	242.860	0·18	0·01	
„ 22 . .	277,000	0·18	0·01	
„ 30 . .	320,000	0·18	0·01	
Oct. 6 . .	375,000	0·18	0·01	
„ 13 . .	429,000	0·18	0·01	
„ 20 . .	484,000	0·18	0·01	
„ 27 . .	538,000	0·18	0·01	
Nov. 3 . .	577,800	0·18	0·01	
„ 10 . .	617,800	0·18	0·01	
„ 17 . .	657,500	0·18	0·01	
„ 23 . .	712,300	0·18	0·01	
Dec. 1 . .	768,100	0·18	0·01	
„ 8 . .	821,970	0·18	0·01	
„ 15 . .	875,000	0·18	0·01	
„ 22 . .	929,470	0·18	0·01	
„ 29 . .	1,024,500	0·18	0·01	
1861				
Jan. 9 . .	1,121,100	0·18	0·01	
„ 19 . .	1,214,000	0·18	0·01	
„ 26 . .	1,278,000	0·18	0·01	
Feb. 2 . .	1,342,800	0·18	0·01	
„ 11 . .	1,426,000	0·18	0·01	
„ 16 . .	1,485,000	0·18	0·01	
„ 23 . .	1,543,000	0·18	0·01	
March 2 . .	1,602,000	0·18	0·01	
„ 9 . .	1,661,000	0·18	0·01	
„ 16 . .	1,720,000	0·17	0·01	
„ 23 . .	1,779,000	0·17	0·01	
„ 30 . .	1,829,000	0·17	0·01	
April 6 . .	1,885,000	0·17	0·01	
„ 13 . .	1,945,000	0·17	0·01	
„ 20 . .	2,000,000	0·17	0·01	
„ 27 . .	2,059,000	0·17	0·01	
May 4 . .	2,110,000	0·17	0·01	
„ 11 . .	2,165,000	0·17	0·01	
„ 20 . .	2,250,000	0·17	0·01	
Sept. 4 . .	2,727,754	0·17	0·01	
Oct. 16 . .	3,150,000	0·17	0·01	

At this point, the beam having sustained upwards of three million changes of load without any increase of de-

flection or permanent set, it was assumed that it might have continued to bear alternate changes to any extent with the same tenacity of purpose as exhibited in the foregoing Table. It was then concluded to increase the load from one-fourth to one-third of the breaking-weight; and having laid on four tons, which increased the deflection to ·20 inch, the work was proceeded with in the same order as in the previous experiments.

TABLE V.

Date.	Changes of load.	Deflection, in inches.	Permanent set, in inches.	Remarks.
1861				
Oct. 18 . .	0	0·20		
,, 19 . .	4,000	0·20	0·	
Nov. 18 . .	126,000	0·20		
Dec. 18 . .	237,000	0·20		
1862				
Jan. 9 . .	313,000	... ...	... ...	Broke by tension across the bottom web.

From these experiments it is evident that wrought-iron girders of ordinary construction are not safe when submitted to violent disturbances with a load equivalent to one-third the weight that would break them. They, however, exhibit wonderful tenacity when subjected to the same treatment with one-fourth the load; and assuming that an iron girder bridge will bear with this load 12,000,000 changes without injury, it is clear that it would require 328 years, at the rate of 100 changes per day, before its security was affected. It would, however, be dangerous to risk a load of one-third the breaking-weight upon bridges of this description, as according to the last experiments the beam broke with 313,000 changes; or a period of eight years, at the same rate as before, would be sufficient to break it. It is more than probable

that the beam might have been injured by the previous three million changes to which it had been subjected; and assuming this to be true, it would then follow that the beam was progressing to destruction, and must of necessity at some time, however remote, have terminated in fracture.

The experiments throw considerable light on this very intricate and very important subject. They are probably carried sufficiently far to enable us to state with certainty what is the safe measure of strength; and as much depends upon the quality of the material and the skill with which the girders are put together, it becomes necessary for the public safety that a measure of strength should be established without encumbering the structures with unnecessary weight. On this question it must be borne in mind that every additional ton that is not required beyond the limits of safety, is an evil that operates as a constant quantity tending to produce rupture; and hence follows the necessity of a careful distribution of the material, in order that the tube or girder may be duly proportioned to the strains it has to bear, and that every part of the structure may have its due proportion of work to perform.

It is assumed, for the sake of illustration, that every description of material, as regards its cohesive properties, will follow the same law in its deterioration under variable strain, when loaded in the same proportion of its ultimate powers of resistance. If this be true, we have only to follow the same rule as observed in the experiments, by loading cast-iron or wooden beams in the ratio of their cohesive powers of resistance, and their breaking-weights respectively. This has not been proved experimentally, but I hope at some future time to have an opportunity of extending the experiments, in order to determine to what extent these views are correct.

The Lords Commissioners of Trade, in the exercise of their functions as conservators of the public safety, have adopted the rule that no railway bridge composed of wrought-iron shall exceed with its heaviest rolling load a strain of five tons per square inch of section upon any part of the bridge. The formula for this maximum of strain upon the materials has been deduced from my own experiments on the model tube at Millwall.

Assuming the top of the girder to be sufficiently rigid to prevent buckling by compression, the formula for the strength of the bottom section derived from these experiments is

$$W = \frac{adc}{l},$$

where the constant $c = 80$.

Applying the formula to the beam experimented upon, we have

a, the area of the bottom $= 2{\cdot}4$ inches,
d, the depth of the beam $= 16$ inches,
c, the constant deduced from the model tube $= 80$,
l, the span or distance between the supports $= 240$ in.

Hence $$W = \frac{2{\cdot}4 \times 16 \times 80}{240} = 12{\cdot}8 \text{ tons},$$

the ultimate strength of the beam.

In order to determine the strain per square inch in these experiments, we find

$$S = \frac{lw}{4ad},$$

where S represents the strain per square inch upon the section a, produced by the greatest load w, laid upon the middle of the girder.

It is necessary to observe that in a girder properly proportioned, the greatest strain per square inch will take place upon the bottom section; so that if the strain upon

the bottom section of such a girder be within the Government Commissioner's condition of safety the strain upon the top section will necessarily be within that limit also. In a girder having the cellular structure at its top section, the area of the top section should be very nearly once and a quarter that of the bottom section, or the areas of their sections should be respectively as $5:4$; and the strain per square inch upon these parts will be respectively inversely as their areas; that is, the strain per square inch upon the top section will be $\frac{4}{5}$ths of the strain per square inch upon the bottom section. In one of the foregoing experiments, we have

l, the length of the girder $=240$ inches,
w, the weight laid on the middle $=2{\cdot}96$ tons,
a, the area of the bottom section $=2{\cdot}4$ inches,
d, the depth of the girder $=16$ inches;

therefore $$S=\frac{240\times 2{\cdot}96}{4\times 2{\cdot}4\times 16}=4{\cdot}62 \text{ tons},$$

the strain per square inch on the bottom section of the girder.

Applying this formula to the whole series of experiments, we obtain the following summary of results :—

TABLE VI.—SUMMARY OF RESULTS.

First Series of Experiments.

Beam 20 feet between the supports.

No. of Experiment.	Date.	Weight laid on middle of beam, in tons.	Number of changes of load.	Strain per square inch on bottom flange.	Strain per square inch on top flange.	Deflection, in inches.	Remarks.
1	From March 21 to May 14, 1860 . . .	2·96	596,790	4·62	2·58	·17	
2	From May 14 to June 26, 1860	3·50	403,210	5·46	3·05	·23	
3	From July 25 to July 28, 1860	4·68	5,175	7·31	4·08	·35	Broke by tension at a short distance from the centre of the beam.

The number of 1,005,175 changes was attained before fracture, with varying strains upon the bottom flange of 4·62 tons, 5·46 tons, and 7·31 tons per square inch.

TABLE VII.—SUMMARY OF RESULTS.

Second Series of Experiments.

Beam repaired.

No. of Experiment.	Date.	Weight laid on middle of beam, in tons.	Number of changes of load.	Strain per square inch on bottom flange.	Strain per square inch on top flange.	Deflection, in inches.	Remarks.
4	August 9, 1860 .	4·68	158	7·31	4·08	—	The apparatus was accidentally set in motion.
5	August 11 and 12	3·58	25,742	5·59	3·12	·22	
6	From August 13, 1860, to October 16, 1861 . . .	2·96	3,124,100	4·62	2·58	·18	
7	From October 18, 1861, to January 9, 1862 . . .	4·00	313,000	6·25	3·48	·20	Broke by tension as before, close to the plate riveted over the previous fracture.

Here the number of 3,463,000 changes was attained when fracture ensued.

From the foregoing it is evident that wrought-iron girders, when loaded to the extent of a tensile strain of seven tons per square inch, are not safe, if that strain is subjected to alternate changes of taking off the load and laying it on again, provided a certain amount of vibration is produced by that process; and what is important to notice is, that from 300,000 to 400,000 changes of this description are sufficient to ensure fracture. It must, however, be borne in mind that the beam from which these conclusions are derived had sustained upwards of 3,000,000 changes with nearly five tons tensile strain on the square inch, and it must be admitted from the experiments thus recorded that five tons per square inch of tensile strain on the bottom of girders, as fixed by the Board of Trade, appears to be an ample standard of strength.

As regards compression, we have only to compare for practical purposes the difference between the resisting-powers of the material to tension and compression, and we shall require in a girder without a cellular top from one-third to three-fourths more material to resist compression than to resist tension; and, as the strength of wrought iron in a state of compression is to its strength in a state of tension as about 3 to $4\frac{1}{2}$, the area of the top and bottom will be nearly in that proportion, or, in other words, it will require that much more material in the top than the bottom to equalise the two forces.

In the experimental beam the area of the top was considerably in excess of that of the bottom, it having been constructed on data deduced from the experiments on tubes without cells; which required nearly double the area on the top to resist crushing. In the construction of large girders, where thicker plates are used, this proportion no longer exists, as much greater rigidity is obtained in the thicker plates, which causes a closer approxi-

mation to equal areas in the top and bottom of the girder; and from this we deduce that from one-third to three-fourths, and in some cases one-third additional area in the top has been found, according to the size of the girder, sufficient to balance the two forces under strain.

The preceding experiments, however, were instituted to determine the safe measure of strength as respects tension, and it will be seen that in no case during the whole of the experiments was there any appearance of the top yielding to compression.

It will be observed that the summaries exhibit the strains per square inch on the top and bottom flanges without deducting the area of the rivet holes, and there being four ½-inch diameter in the bottom flange, two in each angle iron, and two in the plate, is equal to ·625 square inches, which reduces the area for tension from 2·4 to 1·775 square inches. In the calculations I have not, however, made these deductions, in order that the experiments might compare with others where they have not been taken into account. Under the conditions of reduced area, it will be found that the strains per square inch upon the bottom flange, with the variable load, according to formula, will be as follow:—

TABLE VIII.

Number and Date of Experiment.	Weight on Middle of Beam in Tons.	Number of Changes.	Strain per square inch on bottom Flange in Tons.
1st Experiment, May 14, 1860	2·96	596,790	6·25
2nd Experiment, June 26, 1860	3·50	403,210	7·39
3rd Experiment, July 28, 1860	4·68	5,175	9·88
Beam Repaired.			
1st Experiment, August 9, 1860	4·68	158	9·88
2nd Experiment, August 12, 1860	3·58	25,742	7·56
3rd Experiment, October 16, 1861	2·96	3,124,100	6·25
4th Experiment, January 9, 1862.	4·00	313,000	8·45

From Table VIII. it will be seen that the actual strain upon the solid plate was considerably increased. And the beam broke in the first series with a strain of nearly 10 tons upon the square inch; and in the second with a strain of $8\frac{1}{2}$ tons, after sustaining 3,463,000 changes of load. Hence it may be inferred that a wrought-iron bridge would be perfectly safe for a long series of years, with a strain of 6 tons per square inch, or one-fourth the statical breaking weight. It is, however, evident from these experiments that time is an element which enters into the resisting powers of materials of every description when subjected to a continued series of changes. These may be very minute, but assuming them to be of sufficient force to produce molecular disturbance, it then follows that rupture must eventually ensue.

APPENDIX.

ON SOME OF THE CAUSES OF THE FAILURE OF DEEP SEA CABLES.*

THE author stated that the recent disaster and loss of the greater portion of the Atlantic cables is one of those casualties which may be considered national, and looked upon as a misfortune much to be regretted. It is, however, suggestive of improvements, and the removal of impediments which seem to have beset the last attempt to submerge what was considered the best and most effective cable ever constructed for a durable telegraphic communication between this country and America.

The cable was unanimously selected by the scientific committee, to whom was entrusted a long series of experiments to determine its strength, and other chemical and electrical properties of the materials of which it was composed.†

It will be noticed that the failure of insulation, submergence, &c., is not an uncommon occurrence; on the contrary, it has been estimated that out of about 14,000 miles of cable that have been laid, nearly three-fourths of that length have been failures, and that at the present

* Abstract of Mr. Fairbairn's report to the British Association, vide Report of the British Association for 1865, page 178.

† Vide pages 244 to 289.

time not more than 4,000 to 5,000 miles are in successful operation.

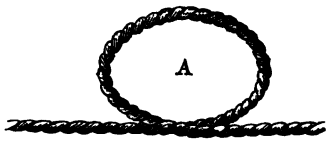
There are two things in marine telegraphy which require special attention, viz. the manufacture of the cable, and its submergence in deep water. In this inquiry the author assumes the conducting wires, insulation, and strength of the cable to be satisfactory, and nothing more remains to be done but to lay it quietly on the bed of the ocean. The recent loss of this cable, and the imperfect insulation of others, are, however, important lessons, which prove the necessity of the most vigilant inspection of every inch of cable as it is manufactured, in the first instance, and its careful preservation until it is safely deposited on its permanent bed, in the second. Every possible care was taken in this case; but notwithstanding the precautions exercised by the manufacturing company, small pieces of wire on three different occasions were found sticking to the cable, and in contact with the conducting wires, which proved destructive of the insulation. These apparently trifling circumstances were the whole and sole cause of the loss the company and the public have sustained in the failure of this important enterprise.

A voyage from the Nore to Valencia in July last —1865—presented opportunities for examining the big ship, with her machinery and valuable cargo. The paying out machinery was perfect, as it proved itself to be, in regard to its powers for regulating the slack to be paid out at different depths, and the uniform degree of tension requisite to be observed in paying out the cable at great depths.

Paying out a cable of considerable weight and strength from the coil seems to be surrounded with some difficulties, the greatest of which is the danger of kinks arising from the twist which it receives in being uncoiled. This

is the great objection to every description of cable paid out from the coil, as the tendency is to run into loops, such as shown at A, fig. 55, and this when submitted to an amount of tension of not more than one-half its ultimate powers of resistance, would injure the insulation, and what is more than probable, would ultimately destroy the conductivity of the cable.

Fig. 55.



These are difficulties which, in this weight of cable and large diameter of coils in the tanks have been overcome. With a smaller cable (carefully insulated) depending entirely upon the conducting wires for its strength, it might be possible to wind it in lengths of 80 to 100 miles upon reels, and these neatly balanced in the hold of the ship, might be paid into the sea entirely free from kinks; but in doing this it must be observed that considerable risk is incurred of breaking the cable from the amount of friction to which the wheels would be subject when loaded with 80 miles of cable. Taking the whole conditions of these arrangements into account, it is not clear that the reels would be any improvement upon the large coils in tanks, as adopted in the 'Great Eastern' ship. In fact there is no other plan suitable for the paying out of the Atlantic cable of its present weight and dimensions but the coil.

With regard to the 'Great Eastern' ship, he stated that she proved herself everything that could be wished for. Her easy steady motion was just what was required for paying out the cable, and its relief from undue strain by the absence of pitching, renders the ship exclusively calculated for the submergence of submarine cables in deep water. She is the very thing that is wanted for such a purpose, and he firmly believed, if she were pro-

perly fitted and prepared for such a service—with some additional stringers to strengthen the upper deck and sides*—she would find full employment as a submerger of cables in every sea which divides the four quarters of the globe. She is admirably adapted for such a purpose, and her double engines, with screw and paddles, assist the steering, and afford great facilities for paying out and hauling in the cable, should accidents occur such as overtook the vessel in the middle of the Atlantic.

The author further remarked that the recovery of a lost cable is at all times a precarious operation, and the difficulties which present themselves in the case of the Atlantic cable, are its large diameter and the friction of its external surface in passing through the water. If raised at all it must be at an exceedingly slow speed, and that with one end loose, otherwise he should despair of raising it from a depth of 2,100 fathoms, by hooking it in the bight or middle, where the resistance would be doubled in raising two sides instead of one.

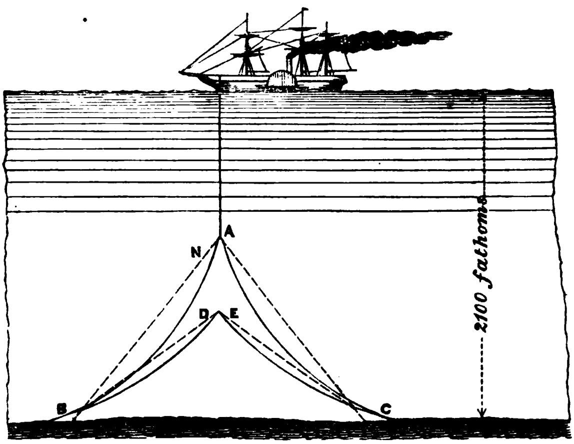
Supposing the cable to be hooked by the grapnel a few miles distant from the fracture, it will then be seen (if it is to be raised from a depth of $2\frac{1}{4}$ miles) that the present cable would have to be lifted at an angle of about 45° on each side, or 3·18 miles of cable = $6·25 \times 14$ cwt. (the weight of the cable in water), a weight of $4\frac{1}{3}$ tons, or equivalent to more than one-half the breaking strain. To this dead weight must be added the friction of the two sides AB, AC, of the triangle ABC, fig. 56, which will be as the squares of the velocities with which it is raised. What may be the additional amount of strain from the speed with which it may be drawn through the water it

* The Author had been informed that the vessel had been weakened in those parts by cutting a longitudinal stringer on each side at midships to make room for the tanks, which on subsequent inquiry was found incorrect.

is not necessary here to calculate, as it is obvious that at a rate of two miles per hour it would approximate close upon the breaking weight of the cable.

Assuming, for the sake of calculation, the strain, including weight and friction, to be 6 tons, and as it requires a strain of $7\frac{3}{4}$ tons to break the cable, there is left

FIG. 56.



in reserve $1\frac{3}{4}$ tons, to carry the bight of the rope to the surface of the water. Now this is assuming that the cable has been paid out with as much slack as will enable it to be raised in the manner just described, but this not being the case, any attempts at raising the cable after this method would break it. In order that it might reach the surface, the slack of 1,100 yards on each side would require to be taken up, and this could only be obtained by a drag for five miles, which would increase the resistance to such an extent as to fracture the cable. This is evident from the fact that the excess of cable paid out over the distance run was 1210 : 1060, or $12\frac{1}{2}$ per cent. of slack,

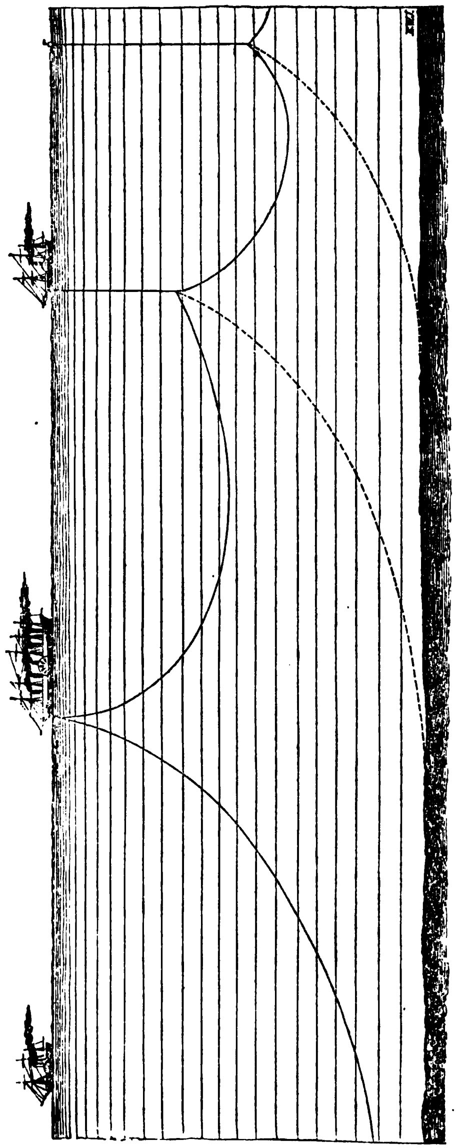
which is equivalent to dragging some miles of cable through the ooze or mud to make up the difference between the catenaries D, E, and AB, AC.

According to this reasoning, it would appear that any attempt to raise the cable in this way would prove fruitless unless some means were adopted to cut it at the point N on the American side, and haul in by a second grapnel, which would hold fast until the cable was brought to the surface.

Since the above was written, the author has been in communication with the engineers and others connected with the Construction and Maintenance Company, who are now constructing an entirely new cable similar to that of last year, excepting only that the wires are galvanized, and the hemp covering is not saturated with tar. This new cable will be attached to the shore ends at Valentia and Newfoundland; and should this expedition be successful, the 'Great Eastern' and her two consorts will be enabled to return to the spot where last year's cable parted, and by the usual means of grapnels to fish it up, and splice to it as much of the new cable as will carry it forward to Newfoundland. Thus it is confidently expected that two cables will be the important result of this year's undertaking. Considerable difference of opinion appears to exist as to the ultimate success of these critical operations, but as every precaution is taken in having improved machinery for picking up and hauling in, under the direction of Mr. Canning, the Construction and Maintenance Company's engineer, the prospect of success is much more encouraging than at any former period in the history of this important enterprise. It is, moreover, intended to employ two more vessels with proper apparatus for grappling the cable in three places about one or two miles apart, in order to relieve the strain, and to hold on by buoys until the cable is cut and hauled on board.

DIAGRAM SHOWING THE PROPOSED METHOD TO BE OBSERVED IN RAISING THE LOST CABLE OF 1861.

Fig. 57.



Bottom of the Atlantic.

We are now—September 1866—in a position to state that the cable of last year has been recovered, and is successfully at work between Valentia and Newfoundland. The means adopted for that purpose is somewhat similar to that already described, three vessels being employed instead of two, as may be roughly shown in the diagram fig. 57, which indicates the series of lifts which took place.

This nearly agrees with the report of the *Times* Correspondent, who describes the process by which it was grappled and raised to the surface.* The recovery of

* It must be remembered that from repeated soundings taken for the purposes of the telegraph, no ocean bed is so well known to us as the bottom of the Atlantic. Where the cable was grappled for it is covered with a soil composed literally of minute shells of the *diatomaceæ tribe*, so minute, in fact, as to be only visible under a microscope, and so fine in their organisation as to prove that not the slightest motion can exist at those depths, for otherwise their delicate formation would be destroyed. On these the cable has laid harmlessly as on a bed of sand, and the grapnels at once caught it. The 'Great Eastern' and the 'Medway' did not arrive on the searching ground till the 12th of the month, and, after preliminary arrangements had been made for the working in concert, the 'Great Eastern' on the evening of the 15th, caught and raised the cable more than 500 fathoms. In the act of buoying it the buoy rope again slipped, and it was again lost. On the second day she caught it again, and this time brought it to the surface. In the act of bringing it over the bows the grapnel surged, and the wire again plunged down to its resting place, three miles beneath the ships. Once more within two days, it was raised by the 'Great Eastern,' while the 'Albany' to the west caught and broke it, and all the work had to be begun again. On the 26th, the 'Medway' caught it and brought it up one thousand fathoms, when, the sea being rough, and the strain on the grapnel sudden and violent from the pitching of the vessel, the rope broke. On the evening of the same day, however, the 'Albany' caught it again and brought it to the surface, and the 'Great Eastern,' to make assurance doubly sure, got two miles of it on board and securely buoyed what was outside the vessel. The work of making the splice at once commenced, but not where the wire was fastened to the buoy. The 'Great Eastern,' on the contrary, under-ran the wire to a considerable distance to the east, in order to get rid of the tangle in which the different buoys and grapnel ropes must have involved its Western extremity. After this necessary pro-

this cable from such immense depths may be considered one of the most successful triumphs of marine engineering ever accomplished, and we may safely congratulate the Construction and Maintenance Company and their engineers on this fortunate event.

cess, some eighty miles of the wire were abandoned. The 'Great Eastern' has now (Wednesday) about four more days' steaming to bring her safely into Heart's Content Bay. Already she has passed the deepest water on her route; in fact the very deepest water she can encounter was that from which she raised the cable of last year. All fear, therefore, as to the safety of the line may be considered at an end, and by Sunday next at latest, the shareholders will be in possession of two perfect lines. How much they may be congratulated on this may be guessed from the fact that their present line, which is steadily increasing in its returns, is already earning money at the rate of 900,000*l.* a year. If there be any one individual to whom more than another the chief credit of the enterprise belongs, it is certainly Mr. Glass. On him have mainly fallen the labour and the loss, and to him is due the honour of success.

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